DOI: https://doi.org/10.14256/JCE.4121.2024

Građevinar 2/2025

Primljen / Received: 25.8.2024.
Ispravljen / Corrected: 25.1.2025.
Prihvaćen / Accepted: 1.2.2025.
Dostupno online / Available online: 10.3.2025.

Passively safe poles along roads as a measure to increase traffic safety

Authors:

Assoc.Prof. **Višnja Tkalčević Lakušić**, PhD. CE
University of Zagreb
Faculty of Civil Engineering
visnja.tkalcevic.lakusic@grad.unizg.hr
Corresponding author

Prof. **Darko Babić**, PhD. Traff.Eng.
University of Zagreb
Faculty of Transport Sciences
darko.babic@fpz.unizg.hr

Subject review

Višnja Tkalčević Lakušić, Darko Babić

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The intention of this paper is to try to influence the reduction of serious consequences in the case of traffic accidents that occur due to the collision of vehicles with poles along the roads. The paper explains the problem related to the existing equipment along the roads in the event of a vehicle collision and analyzes the safety of traffic on Croatian roads. As one of the measures to increase road safety, the possibility of using passively safe infrastructure, especially lighting poles, as an alternative to the existing equipment was presented. The properties that columns must satisfy in order to be considered passively safe according to the EN 127676:2019 standard are shown. The justification of the application of certain types of passively safe columns for a specific location was analyzed, considering the possibility of energy absorption.

Key words:

roads, traffic safety, passively safe poles, energy absorption, vehicle crash

Pregledni rad

Višnja Tkalčević Lakušić, Darko Babić

Pasivno pouzdani stupovi uz ceste kao mjera povećanja razine sigurnosti u prometu

Intencija je ovog rada pokušati utjecati na smanjenje teških posljedica prometnih nesreća do kojih dolazi zbog udara vozila u stupove uz ceste. U radu je objašnjena problematika vezana uz postojeću opremu uz ceste pri udaru vozila i analizirana sigurnost prometa na hrvatskim cestama. Kao jedna od mjera povećanja razine sigurnosti na cestama prikazana je mogućnost primjene pasivno pouzdane infrastrukture, posebno rasvjetnih stupova, kao alternative postojećoj opremi. Prikazana su svojstva koja trebaju zadovoljiti stupovi kako bi se smatrali pasivno pouzdanima prema normi EN 127676:2019. Analizirana je opravdanost primjene pojedine vrste pasivno pouzdanih stupova za određenu lokaciju s obzirom na mogućnost apsorpcije energije.

Ključne riječi:

ceste, sigurnost u prometu, pasivno pouzdani stupovi, sudar vozila, apsorpcija energije

1. Introduction

Road crashes cause serious consequences, including injuries, loss of life and material damage. Statistics indicate that around 20 % of road traffic fatalities result from vehicles leaving the roadway and colliding with fixed roadside objects [1]. Nearly half of fatalities in fixed-object crashes occur at night and involve drivers under the influence of alcohol. Speeding, fatigue, inattention and poor visibility also contribute to such crashes.

In 2022 alone, 8,697 people died in collisions with roadside objects in the USA, as shown in Table 1. In the European Union (EU), 6,369 fatalities occurred in single-vehicle crashes (it can be said that the majority of these crashes were collisions with roadside objects) in the same year (Table 2), which is 35 % of all deaths in the EU roads [2]. According to statistics [3], collisions between vehicles and roadside objects affect 18 to 42 % of all fatal crashes.

In the Republic of Croatia, according to data from the Ministry of the Interior, collisions with fixed roadside objects made up around 8 % of all traffic crashes in recent years (more precisely, in 2021, 8.1 %; in 2022, 8.2 %; in 2023, 8.7 %) [4]. The proportion of fatal crashes involving roadside objects was 5.3 % in 2021, 4.5 % in 2022, and 6.0 % in 2023. The proportion of crashes in which people were injured in collision with fixed roadside objects in relation to the total number of crashes with injured participants was about 4 %.

The most common fixed objects involved in fatal crashes are trees and roadside poles [5]. According to statistics [1], in fatal crashes, the most common objects that vehicles hit are trees (3836 fatalities, 44 %), roadside poles (1027 fatalities, 12 %), and guardrails (844 fatalities, 10 %), Figure 1.

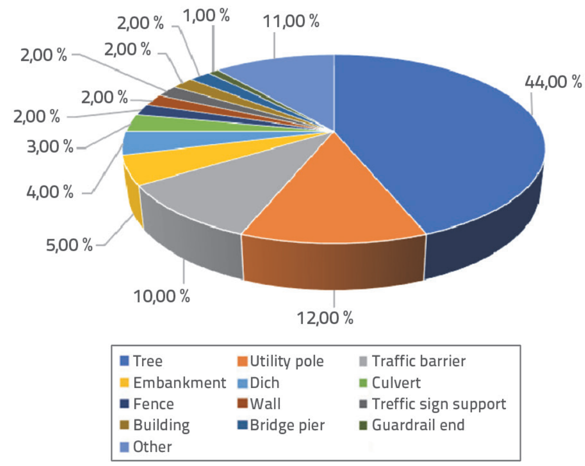

Figure 1. Proportion of fatalities in a collision with a solid object by type of object [1]

Table 1. Data of fatalities in crashes in the USA 2005-2022 [1]

Year	Fatalities involved fixed objects		Other fatalities		All fatalities	
	Number	[%]	Number	[%]	Number	[%]
2005	9176	21	34,334	79	43,510	100
2006	9303	22	33,405	78	42,708	100
2007	9289	23	31,970	77	41,259	100
2008	8792	23	28,631	77	37,423	100
2009	7928	23	25,955	77	33,883	100
2010	7529	23	25,470	77	32,999	100
2011	7378	23	25,101	77	32,479	100
2012	7697	23	26,085	77	33,782	100
2013	7553	23	25,341	77	32,894	100
2014	7518	23	25,226	77	32,744	100
2015	7700	22	27,785	78	35,485	100
2016	8039	21	29,767	79	37,806	100
2017	7875	21	29,598	79	37,473	100
2018	7465	20	29,370	80	36,835	100
2019	7308	20	29,047	80	36,355	100
2020	8622	22	30,385	78	39,007	100
2021	8904	21	34,326	79	43,230	100
2022	8697	20	33,817	80	42,514	100

Table 2. Fatalities in single-vehicle crashes by EU27 and EFTA countries (2012-2022) according to the CARE database [2]

Country	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	LT*	ST*
Belgium	312	322	282	310	265	223	222	250	201	190	204	-35 %	-18 %
Bulgaria	199	221	214	217	234	193	176	173	139	209	162	-19 %	-6 %
Czech Republic	243	197	220	235	186	166	176	204	160	167	186	-24 %	-9 %
Denmark	-	-	46	48	54	49	39	58	53	34	46	-	-21 %
Germany	1102	987	995	958	895	927	960	899	874	789	895	-19 %	0 %
Estonia	-	-	25	-	23	11	21	17	22	19	14	-	-18 %
Ireland	-	-	-	-	-	55	46	48	48	-	-	-	-
Greece	424	372	300	323	320	293	263	264	263	275	281	-34 %	6 %
Spain	672	522	606	589	622	624	613	595	506	544	645	-4 %	8 %
France	410	331	1194	1305	1203	1289	1194	894	744	807	939	129 %	5 %
Croatia	**129**	**104**	**80**	**97**	**87**	**-**	**113**	**-**	**99**	**108**	**118**	**-9 %**	**-**
Italy	1655	1591	1475	1563	1461	1532	1453	1392	1146	1306	1446	-13 %	4 %
Cyprus	22	20	15	24	9	15	16	8	18	18	10	-55 %	-
Latvia	45	49	68	62	46	32	29	41	52	-	-	-	-
Lithuania	-	64	69	59	45	39	43	49	33	38	36	-	-27 %
Luxembourg	17	17	13	17	17	11	19	12	9	9	22	29 %	83 %
Hungary	134	142	129	156	138	125	111	136	106	146	121	-10 %	-11 %
Malta	-	-	-	2	4	1	11	2	3	4	-	-	-
Netherlands	-	-	-	-	-	-	-	-	-	-	-	-	-
Austria	186	142	153	166	151	146	144	116	136	129	145	-22 %	25 %
Poland	847	792	727	670	729	703	728	700	711	627	518	-39 %	-26 %
Portugal	300	234	244	169	230	219	258	280	227	236	251	-16 %	-10 %
Romania	-	-	-	-	-	-	-	-	-	-	-	-	-
Slovenia	24	25	35	46	53	37	36	37	31	44	23	-4 %	-38 %
Slovakia	-	-	-	-	69	79	69	72	83	83	72	-	0 %
Finland	79	105	89	90	107	97	94	81	87	82	69	-13 %	-15 %
Sweden	86	101	70	107	97	100	100	66	74	62	62	-28 %	-6 %
EU	**7147**	**6535**	**7175**	**7361**	**7100**	**7066**	**6934**	**6500**	**5825**	**6026**	**6369**	**-11 %**	**-2 %**
Iceland	6	8	-	9	7	8	10	4	6	5	3	-	-
Liechtenstein	-	-	-	-	-	-	-	-	-	-	-	-	-
Norway	48	71	53	45	55	28	38	36	31	29	38	-21 %	6 %
Switzerland	161	110	94	116	80	99	99	83	109	81	112	-30 %	35 %

LT* = Long-term change compared to 2012.; ST* = Short-term change compared to 2019

Since Croatia lacks official statistics on crashes involving lighting poles, media reports provide insight into such incidents. Headlines include:

- Driver crashed into a concrete lighting pole; firefighters had to extract him from the vehicle [6].
- The force of the impact knocked down a light pole, and the vehicle was destroyed beyond recognition: We barely managed to get the Driver out of the vehicle, who was trapped inside [7].
- CAR UNRECOGNIZABLE Two dead in Medulin; the force of the car's impact broke a light pole [8].

Figure 2 shows the consequences of crashes in which a vehicle crashed into a concrete or metal street light pole along the road's edge.

Collisions of vehicles with poles do not have to be so severe consequences. One way to reduce the consequences of such crashes is to use passively safe poles along roads with different energy absorption properties. Namely, the problem is that when a vehicle hits a pole, it creates much energy. The poles that are usually placed along the roads in the Republic of Croatia are rigid and cannot absorb all the energy, so most of it is transferred to the vehicle and its passengers. This results in the vehicle

Figure 2. Consequences of vehicles hitting roadside poles [6, 8]

Figure 3. Vehicle collision with a passively safe pole [9]

stopping too suddenly at a short distance, negatively affecting the passengers.

By placing poles that would behave differently during the impact, for example, deform and absorb energy, the energy that the vehicle would have to absorb would be significantly reduced, less vehicle deceleration would be achieved, and the safety of the passengers in the vehicle would be increased. For illustration, Figure 3 shows a vehicle collision with a passively safe pole that can absorb energy.

Experience from countries where passively safe poles have been used for about 20 to 30 years, such as the Scandinavian countries, the Netherlands, the UK, and the USA, has shown that the use of this type of pole contributes to a significant reduction in the number of fatalities in crashes [10]. For example, in the UK, between 2002 and 2009, around 26,000 passively safe poles were installed. During that time, no fatality or serious injury to vehicle occupants was recorded in a collision involving a vehicle with this pole type [11].

2. Review of traffic safety in the Republic of Croatia

Preventing crashes and reducing their consequences are key goals in traffic safety. In order to raise the level of safety and traffic culture on Croatian roads, the Croatian Parliament adopted amendments to the Road Traffic Safety Act from 2019 to 2023. The new provisions of this act provide for stricter punishment for perpetrators of the most serious violations that cause the most serious traffic casualties [12]. In addition to the Road Traffic Safety Act, in 2021 the Government of the Republic of Croatia adopted the Decision on the adoption of the National Road Traffic Safety Plan (NPSCP) of the Republic of Croatia for the period from 2021 to 2030 [13]. By 2030, the goal is to get closer to the number of fewer than 148 fatalities. With a fatality rate of 7.1 per 100,000 inhabitants in 2023, Croatia is near the bottom of the European Union list, given that the European Union average is 4.9 fatalities.

In September 2020, the United Nations General Assembly adopted Resolution A/RES/74/299 "Improving global road safety", which proclaimed the "Second Decade of Action for Road Safety 2021-2030", with the aim of preventing at least 50 percent of road deaths and injuries by 2030 [14]. In line with the vision of sustainable development and road safety of the European Union and the United Nations, the NPSCP 2021-2030, a specific goal was set to "Improve road safety in the Republic of Croatia", which directly contributes to the achievement of the United Nations Agenda 2030 for Sustainable Development. Measures are envisaged in 13 areas of action to implement this goal:

1. Safe speed,
2. Driving without the influence of alcohol, drugs and medication,
3. Safe driving,
4. Safety helmet,
5. Vehicle protection,
6. Prevention of driver distraction,
7. Active forms of traffic – pedestrians, cyclists,
8. Safety of motorcycle and moped riders,
9. Safety of professional drivers,
10. **Safe infrastructure**,
11. Safe vehicles,
12. Fast and efficient emergency response services,
13. Strengthening the capacity of traffic police and inspection services.

As a contribution to the measure listed under ordinal number (10) "Safe infrastructure", interventions related to the pavement structure itself and to the equipment installed along the road are taken into account. When considering the pavement structure, in addition to selecting the appropriate layers of the pavement structure depending on the road category, special attention is paid to the final layer of the pavement with regard to the interaction of vehicles and the pavement. In order to ensure the necessary evenness of the road surface depending on the amount of traffic load, the area where the road is constructed with regard to temperatures, and to prevent the occurrence of ruts, asphalt and concrete final layers are used [15-18]. In order to increase traffic safety, great attention is also paid to the quality of horizontal signaling on the road surface [19]. When considering the equipment installed along the road, the use of passively safe poles is one of the best measures for increasing traffic safety. Namely, when a vehicle hits such a type of pole, they fail in a controlled manner, which reduces injuries to vehicle passengers and other road users. For this measure, the recommendation is to gradually replace existing rigid poles with passively safe poles.

Given that the Republic of Croatia does not officially monitor statistics on vehicle impacts on public lighting poles, in this context, data on crashes recorded as "vehicle impact on roadside objects" may be useful. The percentages of such crashes, listed in the introductory part, show that there is indeed room for improvement of road infrastructure, which is also in line with the previously mentioned areas of the NPSCP.

For the purposes of further analysis, according to data [4], a sample of 8,152 crashes was observed in the period from 2021 to 2023. Most "vehicle impacts on roadside objects" occurred on straight road sections (about 41 %) and on curves (about 24 %), on sections of the road where traffic is controlled by traffic signs or traffic rules. About 15 % of crashes occurred in the intersection area. In the area where traffic is controlled by traffic lights, about 2 % of the total number of "vehicle collisions with objects next to the road" occurred. Furthermore, such crashes occurred most frequently at a speed limit of 50 km/h (more than 63 %). When observing visibility conditions, these crashes were equally distributed in daytime and nighttime conditions.

Then, when it comes to the presence of public lighting in the analyzed crashes, 36 % of them occurred in places where public lighting was in operation, 38 % where public lighting was not in operation, and in 20 % public lighting was not present. For 6 % of crashes, there was no available data on lighting at the time of the crashes. However, it follows from the above that in as many as 74 % public lighting was present along the road, which may be indicative data, but also expected, considering that most of these crashes occurred within settlements.

The above data could be useful when defining parameters for the application of measures to increase infrastructure safety using passively safe poles.

3. Passively safe poles according to EN 12767:2019

3.1. General considerations

The calculation of passively safe lighting poles along roads in Europe is carried out according to the EN 40 standard, while the assessment of passive safety is conducted in accordance with the EN 12767:2019 standard. EN 12767:2019 defines passive safety levels and prescribes rules for conducting and interpreting crash test results under different impact conditions and vehicle speeds. The EN 12767 passive safety standard is continuously analyzed and adjusted approximately every 5-10 years, with the latest revision occurring in 2019.

According to the previous edition, EN 12767:2007, pole classification was based on three parameters: vehicle speed at the moment of impact, the energy absorption capability of the pole and the occupant safety level. In the revised and currently valid EN 12767:2019 standard, the classification of poles concerning passive safety is based on seven parameters:

- Impact speed
- Energy absorption capability
- Occupant safety level
- Backfill type of foundation for the poles
- Collapse mode
- Direction class
- Roof indentation risk.

3.2. Parameters for assessing passive safety

3.2.1. Impact speed

The impact speed class indicates the speed of the vehicle at the time of the test crash. According to the EN 12767 standard, two types of test crashes are required, at low speeds of 35 km/h and at higher speeds, which can be 50, 70 or 100 km/h. The crash tests are conducted using a standard passenger vehicle with a mass of 900 kg and various pole foundation types.

Low-speed crash tests are necessary to ensure the structure functions properly. High-speed crash tests help assess the failure mode of poles, their energy absorption capability upon impact, and their effects on the vehicle and its occupants.

3.2.2. Pole categories based on energy absorption capacity

Considering the ability to absorb energy, passively safe poles can be divided into three categories according to EN 12767:2019:

- HE poles (high energy absorbing) – poles that absorb large amounts of energy,
- LE poles (low energy absorbing) – poles that absorb limited amounts of energy,
- NE poles (non-energy absorbing) – poles that do not absorb energy.

The behavior of these poles during a vehicle impact is illustrated in Figure 4.

High energy absorbing poles (HE poles) significantly reduce the speed of a vehicle after a collision, and in some cases completely stop the vehicle. They are designed to deform in front of and under the vehicle when the vehicle hits the pole, and in some cases, they can wrap around the vehicle.

Low energy absorbing poles (LE poles) reduce the speed of a vehicle slightly after a collision. They are generally designed to fail in front of and beneath the vehicle before detaching from the foundation.

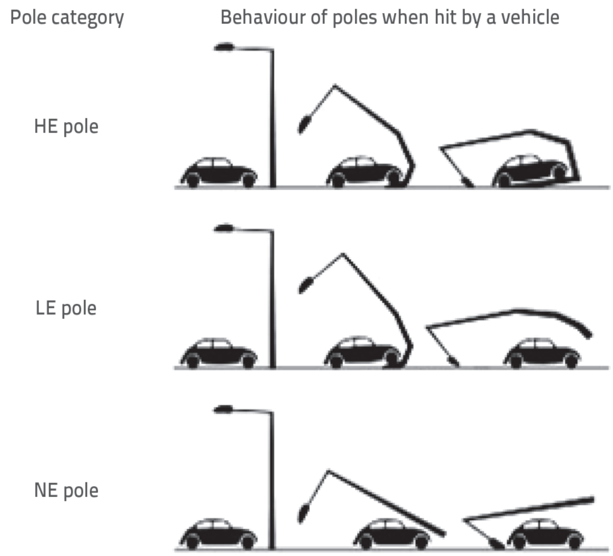

Figure 4. Pole categories based on energy absorption capacity [21]

When a vehicle collides with non-energy absorbing poles (NE), the pole detaches from its base and is thrown over the vehicle, landing near the foundation. The vehicle typically continues moving with a certain speed reduction and relatively minor vehicle damage [22].

Colliding with such poles presents a lower risk of driver injury than energy-absorbing poles, but there is a higher risk of secondary collisions due to the pole falling and the vehicle continuing to move. The behavior of non-energy absorbing poles is illustrated in Figure 5.

To determine the category of a pole with regard to its energy absorption capacity, the vehicle speed at the moment of the test collision (v_i) and the vehicle speed after the test collision (v_e) are measured at a certain distance from the pole and compared with the values shown in Table 3.

3.2.3 Occupant Safety Level

In the revised EN 12767:2019 standard, five occupant safety levels are defined for vehicle occupants upon impact with a pole. These levels are labeled from **A to E**, with **A** representing the highest safety level. This represents a change from the previous EN 12767:2007 standard, which defined four occupant safety levels, labeled numerically from 1 to 4.

Occupant safety levels are determined based on two parameters ASI (Acceleration Severity Index) and THIV (Theoretical Head Impact Velocity). These parameters are derived from results obtained through numerous crash tests.

The ASI value represents the calculated deceleration of the vehicle that affects passengers during impact. It is a measure of impact severity, ranging from 1.4 for the lowest safety level to 0.6 for the highest safety level. The THIV value is the theoretical speed (in km/h) at which a passenger's head impacts the vehicle's interior during a crash. It ranges from 44 km/h for the lowest safety level to 11 km/h for the highest safety level (see Figure 6) [23].

Table 4 shows the corresponding ASI and THIV values that must be achieved during test crashes for each category of poles with regard to the ability to absorb energy.

Figure 5. Behavior of NE pole [9]

Table 3. Pole categories based on energy absorption capacity [20]

Impact speed, v_i [km/h]	**50**	**70**	**100**
Pole category	**Exit speed v_e** [km/h]		
HE	$v_e = 0$	$0 \le v_e \le 5$	$0 \le v_e \le 50$
LE	$0 < v_e \le 5$	$5 < v_e \le 30$	$50 < v_e \le 70$
NE	$5 < v_e \le 50$	$30 < v_e \le 70$	$70 < v_e \le 100$

Table 4. Determining the level of safety for vehicle occupants [20]

Pole category according to energy absorption	Occupant safety level	Speeds (maximum values)			
		Mandatory low-speed crash test 35 km/h		Test crash at speeds of 50 km/h, 70 km/h and 100 km/h	
			THIV km/h	ASI	THIV km/h
HE/LE/NE	E	1,0	27	1,4	44
HE/LE/NE	D	1,0	27	1,2	33
HE/LE/NE	C	1,0	27	1,0	27
HE/LE/NE	B	0,6	11	0,6	11
NE	A	Values for ASI and THIV are not prescribed		No measured values for ASI i THIV	

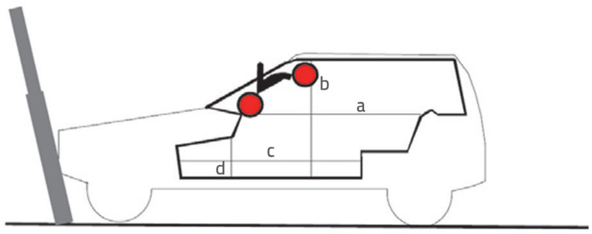

Figure 6. Determining THIV values [21]

3.2.4. Backfill type of foundation for the poles

The backfill type of the pole foundation significantly influences pole behavior. EN 12767:2019 defines three backfill types, shown in Table 5.

Table 5. Backfil type of pole foundations [20]

Type	Type of material
S	Standard soil/aggregate
R	Asphalt or concrete
X	Non-standard foundation

Backfill type **S (Soil)** refers to standard soil/aggregate of a specific composition and density. When using this type of backfill, it is necessary to consider soil heterogeneity, different soil types, and varying groundwater levels, as even temporary rainwater presence can affect soil stability [9].

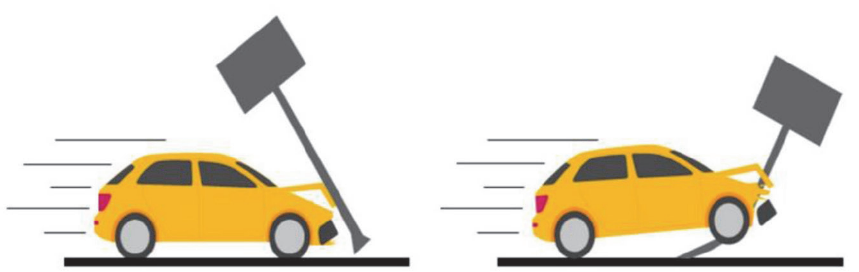

Figure 7. Schematic representations of pole collapse with separation (SE) and without separation (NS) [24]

Backfill type **R (Rigid)** refers to the use of a flat, continuous rigid surface (such as asphalt or concrete) with sufficient thickness to anchor the pole securely. All other types of backfill are classified as **X**, which includes non-standard foundations, such as saturated soil, clay, or gravel.

3.2.5. Collapse mode

The standard distinguishes two collapse modes for poles in case of a vehicle impact. In one case, the pole may separate from the foundation, which is designated as SE (separation), and in the other case, there is no separation, which is designated as NS (no separation), as shown in the figure 7.
SE-classified poles include non-energy absorbing (NE) and low energy absorbing (LE) poles, as they separate from the base upon impact. NS-classified poles include high energy absorbing (HE) poles, as they remain attached to the foundation upon impact. Non-separating collapse is generally a better solution, but it cannot always be applied, especially in the case of non-energy absorbing (NE) poles. The correct choice depends on the specific traffic situation.

3.2.6. Direction class

The direction of impact indicates the angle at which a vehicle can hit a pole in relation to the direction of travel. A 20° angle relative to the travel direction has been adopted as the threshold value, representing the assumed average vehicle departure angle [24].

Standard roadside poles behave the same regardless of the direction of impact. However, some poles may have an additional mechanism, such as a shear failure system for non-absorbing poles (NE poles), so such poles will not behave the same when hit by a vehicle from different directions.
The EN 12767:2019 standard defines three categories of poles based on the direction of impact of the vehicle:

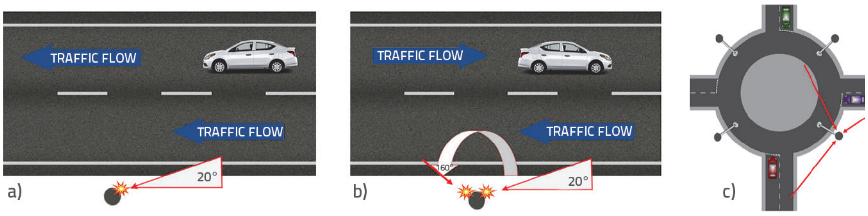

Figure 8. Types of poles according to the direction of vehicle impact [9]: a) Single directional poles; b) Bi-directional poles; c) Multi-directional poles

- SD poles: Single-directional poles
- BD poles: Bi-directional poles and
- MD poles: Multi-directional poles whose behavior does not depend on the angle of impact of the vehicle on the pole.

Single-directional poles (SD) fail in the expected manner if the angle of impact of the vehicle on the pole is less than 20° relative to the direction of travel.

Bi-directional poles (BD) fail in the expected manner if the vehicle impact angle is less than 20° with respect to the two directions of movement, i.e. they behave the same for traffic from the opposite direction (20° and 160°).

Multi-directional poles (MD) fail in the expected manner regardless of the direction from which the vehicle is coming.

Figure 8 shows the types of poles with respect to the direction of vehicle impact.

3.2.7. Roof Indentation Risk

A vehicle collision with certain types of passively safe poles can result in roof indentation, posing a risk to vehicle occupants. According to the EN 12767:2019 standard, two classes are distinguished:

- Class 0, where roof indentations are less than 102 mm, and
- Class 1, where roof indentation is equal to or greater than 102 mm.

Class 0 is recommended but cannot always be achieved. For example, with high energy absorbing (HE) poles, there is a higher risk of roof indentation as these poles can bend around the vehicle.

3.3. Pole marking system

The performance class designation according to EN 12767:2019 consists of seven parameters. The meaning of the designations is shown in Table 6, using the example of pole **100 HE B R NS MD 0**.

For comparison, according to the previous version of the EN 12767:2007 standard, the pole markings contained 3 parameters. For example, the pole marking 100 NE 3 explained that it was a non-absorbing pole, the vehicle speed when hitting the pole was up to 100 km/h, and the occupant safety level was 3. Other passive safety characteristics were described in additional text.

4. Application of passively safe poles

4.1. General considerations

This chapter analyzes the justification for applying different types of passively safe poles on specific road sections. When selecting the type of poles, several factors must be considered, such as the failure mode of the poles, passenger safety, risks to other road users (especially in urban areas), speed limits on the road section in question, the presence of roadside structures such as bridges or walls, and vehicle damage.

4.2. Non-energy absorbing poles (NE Poles)

Non-energy absorbing poles (NE poles) are recommended in areas where high speeds are permitted, and there are no surrounding objects or pedestrians. These poles provide the highest level of safety for vehicle occupants since, after impact, the vehicle continues moving with moderate speed reduction and minimal vehicle damage compared to other pole types. In locations where there is no risk to other road users, this type of pole is the best choice for vehicle occupants, as the impact is typically very short, and the vehicle continues moving after the collision. Non-energy absorbing poles are not recommended near pedestrian zones, bicycle lanes, or trees.

4.3. High energy absorbing poles (HE Poles)

Poles capable of absorbing energy (HE and LE poles) are recommended in locations where there is a risk of secondary collisions and hazards to other road users. High energy absorbing poles can absorb a large amount of energy, resulting in plastic deformation and the pole bending beneath the vehicle. These poles significantly slow down and stop the vehicle, reducing the risk of secondary collisions with roadside objects, trees, pedestrians, and other road users. The risk of passenger injuries

Table 6. Pole markings according to EN 12767:2019 (example of pole 100 HE B R NS MD 0)

100	HE	B	R	NS	MD	0
Speed class	Ability to absorb energy	Occupant safety level	Backfill type	Collapse mode	Direction of impact	Roof Indentation risk
50, 70 or 100	HE, LE or NE	A, B, C, D or E	S, R or X	NS or SE	SD, BD or MD	0 or 1

in a collision with this type of pole is higher than with a non-energy absorbing pole but still lower than with conventional roadside poles.
The use of this type of pole is recommended in locations where there are no obstacles around the poles. When a vehicle collides with this type of pole, it is important to note that the vehicle may continue to move slightly as the pole deforms. A boundary HE pole completely stops the vehicle.

4.4. Low energy absorbing poles (LE Poles)

Low energy absorbing poles share characteristics with both high energy absorbing and non-energy absorbing poles. They are designed so that upon vehicle impact, they fail by yielding in front of and beneath the vehicle before shearing off, similar to non-energy absorbing poles. The speed of a vehicle hitting such a pole will be reduced, and the vehicle damage will be less than in a collision with a high energy absorbing pole. This type of pole is suitable for use on most road categories.

4.5. Secondary risks

In addition to primary risks for vehicle occupants, a collision with a passively safe pole can also pose secondary risks to other road users. This can occur if the lighting pole or part of it falls onto the road after the vehicle impact, or if the vehicle itself continues moving after colliding with the pole. In such situations, the installation of protective barriers is justified.

5. Conclusion

Preventing crashes and reducing their consequences are key objectives in the field of traffic safety. Crashes often result in severe or fatal consequences. One of the most common types of such crashes involves vehicles colliding with objects near the roadway. As noted in this study, from 2021 to 2023, there were 8,152 crashes in Croatia classified as "vehicle collision with a roadside object," most commonly on straight sections (41 %) and in curves (24 %), primarily on roads regulated by traffic signs or rules. These crashes mostly occurred at speed limits of 50 km/h (63 %) and were evenly distributed between daytime and nighttime conditions. Public lighting was present along the road in 74 % of cases, which is expected given that most crashes occurred in urban areas.
It is important to emphasize that crashes involving collisions with roadside poles result in a high number of fatalities and injuries. One way to reduce the consequences of such crashes is the use of passively safe roadside infrastructure, particularly lighting poles with appropriate energy absorption properties upon vehicle impact. This contributes to the "safe infrastructure" measure outlined in Croatia's National Road Traffic Safety Plan (NPSCP).
The selection of passively safe pole types for specific road sections depends on multiple factors, such as failure mode, passenger safety, risks to other road users, speed limits, the presence of roadside objects, and vehicle damage.
Non-energy absorbing poles (NE poles) are recommended in areas with high-speed limits and no nearby objects or pedestrians. They provide the highest level of safety for vehicle occupants and cause minimal vehicle damage compared to other pole types. These poles are not recommended near pedestrian zones, bicycle lanes, or trees. High energy absorbing (HE) and low energy absorbing (LE) poles are recommended in locations where there is a risk of secondary collisions and hazards to other road users.
The classification of passively safe poles according to the revised 2019 standard is based on seven parameters. Consequently, pole labeling has become more detailed compared to previous standards, allowing for better selection of pole types for specific road sections.
Since official statistics in Croatia currently only track crashes classified as "vehicle collision with a roadside object," it would be beneficial to also monitor statistics on vehicle collisions specifically with poles, trees, and other objects. Current crashes database in Croatia does not specify the exact type of object involved in the collision (e.g., fence, lighting pole, tree, or another fixed object), whereas databases in other countries do include such details. By applying modern IT technology, it is possible to enhance these databases within a reasonable timeframe, providing not only more precise records but also a solid foundation for necessary actions to improve road traffic safety.
To enhance traffic safety, further investments in road infrastructure are necessary, along with continuous monitoring of current safety conditions and research activities to identify optimal solutions. While the selection of passively safe poles cannot prevent crashes, it can help save lives and reduce material damage. Finally, it is essential to highlight that road lighting saves many lives each year, despite the risks associated with vehicle collisions with lighting poles, which can be minimized through proper implementation.

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