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The safety of roadside columns in the event of vehicle impact

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Subject review

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Safety of roadside columns in case of vehicle impact

A comprehensive overview of passively safe roadside columns, with an emphasis on materials they are made of and energy absorption properties, is presented in the paper. Levels of passive safety of columns with respect to safety of vehicle occupants are considered. The behaviour of passively safe roadside columns in impact with vehicles is analyzed with respect to their energy absorption possibilities, failure modes and safety of vehicle occupants. Advantages and deficiencies of the use of passively safe columns, as compared to traditional rigid columns that are today most often used alongside roadways, are presented in full detail.

Key words:
roadside columns, safety of columns, vehicle impact, energy absorption, passenger safety

Pregledni rad

Višnja Tkalčević Lakušić

Pouzdanost stupova uz prometnice pri udaru vozila

U radu je dan cjeloviti pregled pasivno pouzdanih stupova uz prometnice s obzirom na materijal izrade i svojstva apsorpcije energije. Razmatrane su razine pasivne pouzdanosti stupova za putnike u vozilu. Analizirano je ponašanje triju tipova stupova pri sudaru s vozilom, i to s obzirom na mogućnost apsorbiranja određene količine energije, način otkazivanja nosivosti i sigurnost putnika u vozilu. Detaljno su prikazane prednosti i nedostaci primjene pasivno pouzdanih stupova u odnosu na tradicionalne krute stupove, koji se danas još uvijek u najvećoj mjeri ugrađuju uz prometnice.

Ključne riječi:
stupovi uz prometnice, pouzdanost stupova, udar vozila, apsorpcija energije, sigurnost putnika

Übersichtsarbeit

Višnja Tkalčević Lakušić

Zuverlässigkeit von Leitpfosten im Falle eines Fahrzeugaufpralls

In der Arbeit wird eine Gesamtübersicht von passiv zuverlässigen Leitpfosten mit Hinsicht auf das Ausarbeitungsmaterial und die Energieabsorptionseigenschaften gegeben. Es werden die Gradierungen der passiven Zuverlässigkeit von Pfosten für die Passagiere in Betracht gezogen. Analysiert wurden drei Pfostentypen bei einem Fahrzeugaufprall, und zwar hinsichtlich der Möglichkeit der Absorption einer bestimmten Energiemenge, Art des Nachlassens der Tragfähigkeit und der Sicherheit der Fahrzeugpassagiere. Die Vor- und Nachteile der Anwendung passiv zuverlässiger Pfosten im Vergleich zu den traditionellen starren Pfosten, die heute noch großteils entlang den Fahrbahnen eingebaut werden sind detailliert dargestellt.

Schlüsselwörter:
Leitpfosten, Zuverlässigkeit der Leitpfosten, Fahrzeugaufprall, Energieabsorption, Sicherheit der Passagiere

1. Introduction

Unfortunately, accidents on roadways are a daily occurrence. According to data from the Ministry of Internal Affairs [1], during the last 10 years there have been 663 thousand traffic accidents resulting in over 6 thousand fatalities, 42 thousand persons seriously injured and 187 thousand persons receiving minor injuries. The roadside columns functioning as lighting columns, traffic lights and traffic signage are very often the subject of vehicle impacts resulting in serious and often fatal consequences, as shown in Figure 1. According to statistics, each year in the world results vehicles collide into roadside columns resulting in the death of thousands of people with hundreds of thousands receiving injuries.

Figure 1. The most serious consequences of a vehicle colliding into a column [2]

In order to reduce the number and degree of traffic accidents caused by vehicles colliding into roadside infrastructure, the European Commission in 2000 proposed the use of passively safe roadside equipment, to include especially lighting columns possessing appropriate energy absorption characteristics during vehicle impact.

The term active or primary vehicle and roadside equipment safety means a design that incorporates the driver and road conditions thus minimising risk of a traffic accident actually occurring. Hence, ABS vehicle systems, rear-vision mirrors, user-friendly instrument panels and well lighted roadways provide safer driving.

On the other hand, passive or secondary vehicle and roadside equipment safety implies that vehicle and roadside equipment are designed to protect vehicle passengers in the event of an accident. Subsequently, passive safety protects passengers during impacts. For instance, modern automobiles are constructed of sophisticated composite materials possessing excellent energy absorption properties in the event of an impact. The question can now be posed in regards to roadside equipment.

As an illustration, Figure 2 shows the consequences of a vehicle colliding at similar speeds into two columns differently constructed. Figure 2.a) shows a vehicle colliding into a standard rigid column as are ordinarily found alongside our roadways, whereas Figure 2.b) shows a vehicle colliding into a deformable column, which is categorised as a passively safe structure.

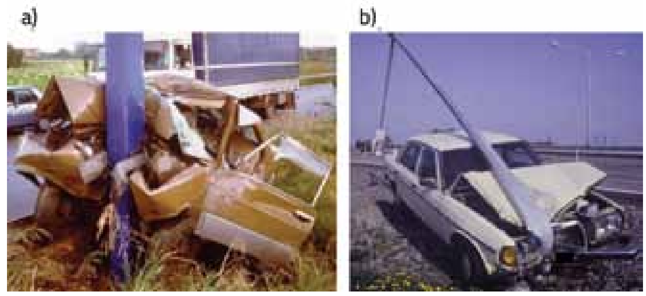

Figure 2. Consequences of a vehicle colliding into various types of columns [3]; a) rigid column, b) deformable column

It is well known that when a vehicle crashes into a column a lot of energy is dissipated. Ordinary rigid column can not absorb energy which is created during impact and almost all the energy is transferred to the vehicle and its occupants. In this case, the vehicle suddenly halts with serious consequences for the vehicle passengers. However, when using a deformable and energy absorbing column, a large amount of energy is dissipated which would otherwise be absorbed by the vehicle during impact, subsequently the deceleration of the vehicle is reduced and passenger safety increases.

2. The effect of column materials in possible energy absorption

Energy absorption during an impact is also affected by materials used in manufacturing the column. Roadside columns are made from wood, reinforced concrete, steel, aluminium and composite materials. When a vehicle crashes into a wooden or concrete column, there is not a lot of column deformation. However, for steel, aluminium and composite columns such deformations are greater due to their ability to absorb more energy during a crash.

The material most often used in constructing roadside columns is steel. The reason for this is the fact that steel columns are relatively lightweight, durable if appropriate anti-corrosive protection is applied, affordable, extremely resistant to fatigue of the material and are completely recyclable.

Research carried out in the Netherlands has shown that aluminium lighting columns are more suitable in the event of an vehicle impact than for instance steel or concrete columns. What happens is that during a vehicle impact, aluminium absorbs 50 % more energy than steel columns possessing the same mass, hence the likelihood of injuries to passengers in the vehicle is significantly reduced [4]. Since aluminium columns are relatively lightweight, almost a third lighter than steel, they are also easier to construct. Aluminium columns do not require maintenance since they do not corrode, hence there is no need for expensive surface protection and the columns have a long lifetime. Aluminium columns have an attractive appearance, are lightweight and flexible, and at the same time are strong and stable. Aluminium is also 100% recyclable, and uses relatively small amounts of energy, while recycling process does not degrade the raw material.

In more recent times, the production of roadside columns utilises composite materials as the most expensive alternative to conventional materials, but which otherwise possesses excellent energy absorption characteristics during an impact. Composite material generally defined as a combination of two or more chemically different materials (metals, ceramics, polymers) and/or forms (fibre, lamina, particles) with a clear boundary connection between the components and properties that are better than the individual components, all for the purpose of achieving the appropriate properties (strength, density, rigidity, hardness).

Besides possessing greater energy absorption, the advantage of composite columns compared to steel or aluminium is less weight and consequently it is easier to assemble, possesses a greater tensile strength and is fire-resistance. Furthermore, composite columns are exceptionally resistant to the unfavourable environment effects (water, chemicals, salt), hence they are less susceptible to corrosion and do not require maintenance.

3. Types of passively safe columns in compliance to EN 12767

An assessment of the reliability of passively safe roadside equipment in European Union countries is carried in compliance to standard EN 12767:2007 - Passive Safety of Support Structures for Road Equipment - Requirements and Test methods [5]. This standard defines levels of passive safety for support structures used for equipment that is situated on roadsides such as columns, protective railings, and so on.

The standard also provides rules for carrying out and interpreting results of crash tests under various crash conditions and vehicle speeds. The requirements stipulate undertaking two types of crash tests:

- a crash test at a speed of 35 km/h in order to ensure proper functioning of the structure at low speeds
- a crash test at a speed of 50, 70 or 100 km/h.

According to EN 12767:2007, passively safe columns classified into three energy-absorption categories:

- High energy absorbing (HE)
- Low energy absorbing (LE)
- Non-energy absorbing (NE).

When determining the energy-absorption column category, vehicle speed is measured at the moment of the crash test and at a particular distance from the column following the crash test. The data is then compared to the values in Table 1, according to [5].

Table 1. Roadside equipment categories for energy absorption [5]

Vehicle speed at impact v_i [km/h]	Vehicle speed following impact v_e [km/h] depending on the column category and energy absorption		
	HE	LE	NE
50	$v_e = 0$	$0 < v_e \leq 5$	$5 < v_e \leq 50$
70	$0 \leq v_e \leq 5$	$5 < v_e \leq 30$	$30 < v_e \leq 70$
100	$0 \leq v_e \leq 50$	$50 < v_e \leq 70$	$70 < v_e \leq 100$

The EN 12767:2007 standard defines four levels of roadside equipment safety for vehicle passengers and other traffic participants during crashes (occupant safety level) ranging from 1 to 4 with the larger indicating a greater level of safety. Levels 1, 2 and 3 indicate an increased degree of safety in reducing injuries received in a crash, whereas level 4 refers to exceptionally safe structures, i.e. small structures that are expected to cause minor vehicle damage in the event of a crash. The standard also defines support structures with no performance requirements for passive safety as Class 0. All other types of structures should be tested in order to determine their behaviour during crashes.

Occupant safety levels are determined using ASI (Acceleration Severity Index) and THIV (Theoretical Head Impact Velocity) values, which are acquired from a large number of crash test results. The ASI value is a vehicle's calculated deceleration value, experienced by vehicle passengers during a crash. This is actually a measure of the severity of a crash and ranges from 1.4 for the lowest safety level to 0.6 for the highest safety level.

The THIV value designates the speed (km/h) at which a passenger's head colliding into the internal vehicle area during a crash, as shown in Figure 3. It ranges from 44 km/h for the lowest safety level to 11 km/h for the highest safety level.

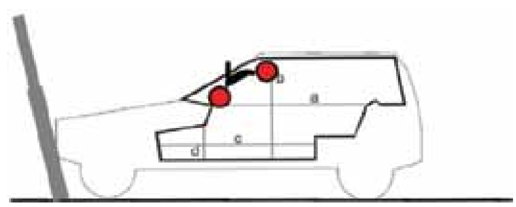

Figure 3. Determining THIV values [5]

In order to determine vehicle occupant safety levels for roadside equipment, crash test results should be compared to the values in Table 2, according to [5].

Finally, performance type of column is determined on the basis of vehicle speed during impact into a column, energy absorption category of column and vehicle occupant safety levels for the column, as shown in Table 3, according to [5].

Table 2. Determining vehicle occupant safety levels for roadside columns [5]

Energy absorption category	Occupant safety level	Speeds			
		Crash test at a speed of 35 km/h		Crash tests at speeds of 50, 70 and 100 km/h	
		Maximum values		Maximum values	
		ASI	THIV [km/h]	ASI	THIV [km/h]
HE	3	1,0	27	1,0	27
	2	1,0	27	1,2	33
	1	1,0	27	1,4	44
LE	3	1,0	27	1,0	27
	2	1,0	27	1,2	33
	1	1,0	27	1,4	44
NE	3	0,6	11	0,6	11
	2	1,0	27	1,0	27
	1	1,0	27	1,2	33

Table 3. Performance type of columns [5]

Parameters taken into consideration	Alternatives
Speed class [km/h]	50, 70 or 100
Energy absorption category	HE, LE or NE
Occupant safety level	1, 2, 3 or 4

According to standard EN 12767:2007, columns are designated in the following manner. For example, the column designation **100 NE 3** means:

100 – vehicle speed in [km/h] during a crash into the column
NE – a column that cannot absorb energy
3 – column safety level for vehicle occupants.

A sheme of the passive safe column classification and the safety level according to [5] is given in the Figure 4.

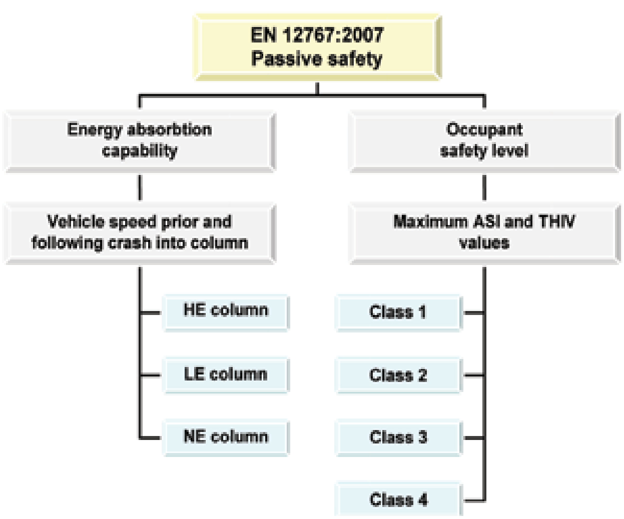

Figure 4. Classification of roadside columns and safety levels according to EN 12767:2007 [5]

4. Behaviour of passively safe columns

4.1. Non-energy absorbing columns (NE columns)

Non-energy absorbing columns (NE columns according to [5]) are designed to shear at the base upon impact, after which the column is thrown above the vehicle and falls to the ground behind the vehicle, as shown in Figure 5. Following the crash, the vehicle continues to move at a reduced speed with relatively minor damage to the vehicle. Subsequently, there is little risk of injury to vehicle passengers. However, there is a greatest risk of a secondary impact by a vehicle into a tree, pedestrians and other traffic participants since the vehicle continues to move and the column falls onto the ground.

Figure 5. Behaviour of a non-energy absorbing column [5]

In order to test and increase the safety of roadside columns, research is being undertaken throughout the world that includes crash tests (in EU countries according to [5]) and numerical modelling.

The behaviour of non-energy absorbing columns is specifically shown in the vehicle crash illustration in Figure 6, which was carried out in the leading European centre in the Netherlands used for testing vehicle safety during crash testing, TTAI (TÜV Rheinland TNO Automotive International) [6]. This testing was carried out for the requirements of a Netherlands company that manufactures steel columns.

Figure 6. An illustration of a crash test using a passively safe non-absorbing column [6]

Crash tests were carried out at vehicle speeds of 35 km/h and 100 km/h for vehicles colliding into a column. In order for the column to meet the classification for a speed of 100 km/h according to [5], it was necessary that following the collision the vehicle would maintain a speed of at least 70 km/h, which was measured 12 metres from the crash position. During the test, the speed was actually 84.8 km/h, i.e. thus exceeding the lower limits. The tests provided measured ASI and THIV values based upon which the vehicle occupant safety level of the test columns was defined.

The time it took for the column to fall to the ground following the vehicle crashing into it was 1.5 seconds. Once the tested column had fallen to the ground, it was possible to see that various columns sections were indented, as shown in Figure 7, but breakage of the column close to the welded positions had not occurred. Following the crash, all parts of the column had fallen behind the vehicle, there was no evidence of deformation on the vehicle roof nor was the windscreen glass smashed, as shown in Figure 8. It is evident that columns possessing such characteristics would inflict significantly less injury to pass-engers in vehicles than if a vehicle had crashed into an ordinary rigid column.

Figure 7. Column details following its fall to the ground [6]

Figure 8. Vehicle following tests [6]

The behaviour of columns that are non-energy absorbing can be seen also in numerical simulations that show the consequences of a vehicle crashing into such a column, as shown in Figure 9. Numerical modelling based on the finite elements method allows modelling with detailed vehicle and column behaviour during a crash. In this way, the manner of determining various column types identified during vehicle crashes at various speeds can be carried out.

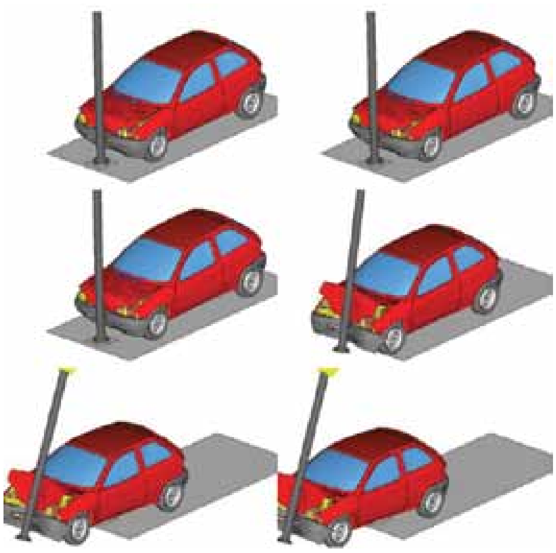

Figure 9. Numerical simulation of a vehicle colliding into a non-energy absorbing column [7]

4.2. High energy absorbing columns (HE columns)

For the case of a car crashing into a column than can absorb large amounts of energy (HE class columns according to [5]), the column experiences plastic deformation and bends under the vehicle, as shown in Figure 10.

Figure 10. Behaviour of a high energy absorbing column [5]

Such columns significantly decelerate and stop a vehicle during impact. Consequently, the risk of a secondary collision by the vehicle into roadside structures, trees, pedestrians and other traffic participants is significantly reduced. However, when a vehicle crashes into high energy absorbing columns, the risk of injury to vehicle passengers is greater in comparison to collisions into non-energy absorbing columns, but is obviously a smaller risk than an collision into an ordinary rigid columns situated along our roads.
The behaviour of high energy absorbing columns during an impact by a car will be illustrated in the example taken from research conducted in Finland [8]. The crash test was carried out in compliance to EN 12767. Composite lighting columns 10, 12.4 and 15 m high were tested in crash tests at vehicle speeds of 35 km/h and 100 km/h. The vehicle used in the test was a Peugeot 205 and allowed ASI and THIV values to be measured. Following the crash tests carried out in Finland, the Russian laboratory Computational Mechanics Laboratory (CompMechLab) aided by the finite elements method compiled numerical simulations of crash tests for a number of types of lighting columns at various vehicle speeds. Lighting columns possessing various heights (10 m, 12.4 m and 15 m) were analysed, including those having various internal and external diameters and various degrees of reinforcement in the composite material structure. The LS-DYNA computer program was used for the purpose of conducting non-linear dynamic analysis for a crash test between a vehicle and column. Three-dimensional models of the columns and vehicles were created, as shown in Figure 11. The analysis also took into account certain non-linearities such as the dynamic effect occurring at various vehicle speeds, plasticity of the column and vehicle parts, interactions upon contact of the simulated vehicle and column, and the progressive damage in column materials.

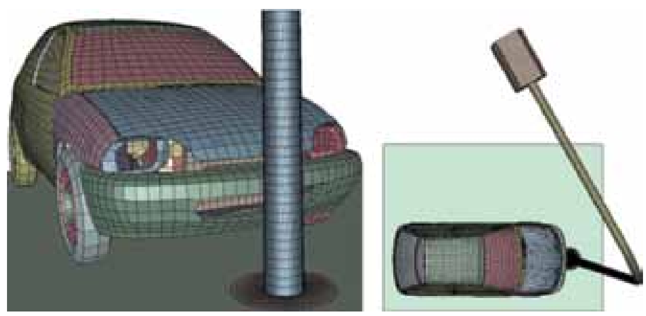

Figure 11. 3-D numerical modelling of vehicle and column [8]

Figure 12 showed a numerical simulation of the behaviour of a composite column and vehicle at a speed of 100 km/h during a crash. It becomes evident that the crash resulted in plastic deformations and bending of the column under the vehicle.

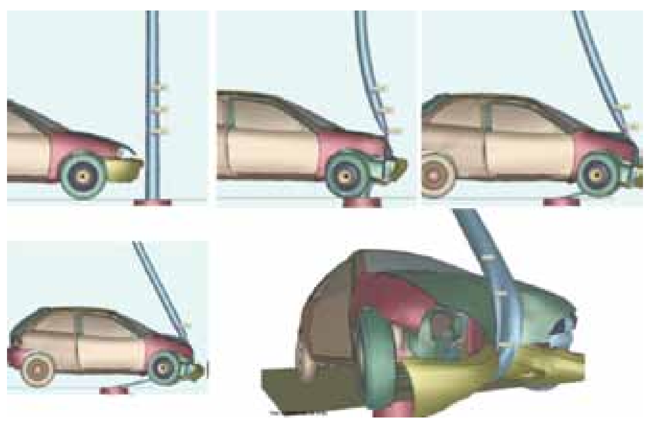

Figure 12. Simulation of vehicle crashing into a column and its deformation under the vehicle [8]

The process of stopping the vehicle from a speed of 100 km/h can be divided into two phases, with the first being the vehicle impact and the second deformation of the column under the vehicle, as shown in Figure 13. The first phase exhibits a greater deceleration. It was shown that this value depends on the cross-section of the column, the external diameter, the number and diameter of reinforcement in the composite material structure. In the second phase, vehicle deceleration leading to its stopping is somewhat less.

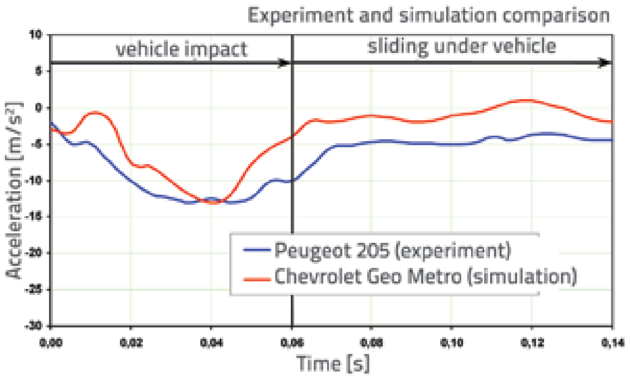

Figure 13. A graph of the vehicle decelerating at a speed of 100 km/h for columns 10 m high during a crash test and numerical simulation [8]

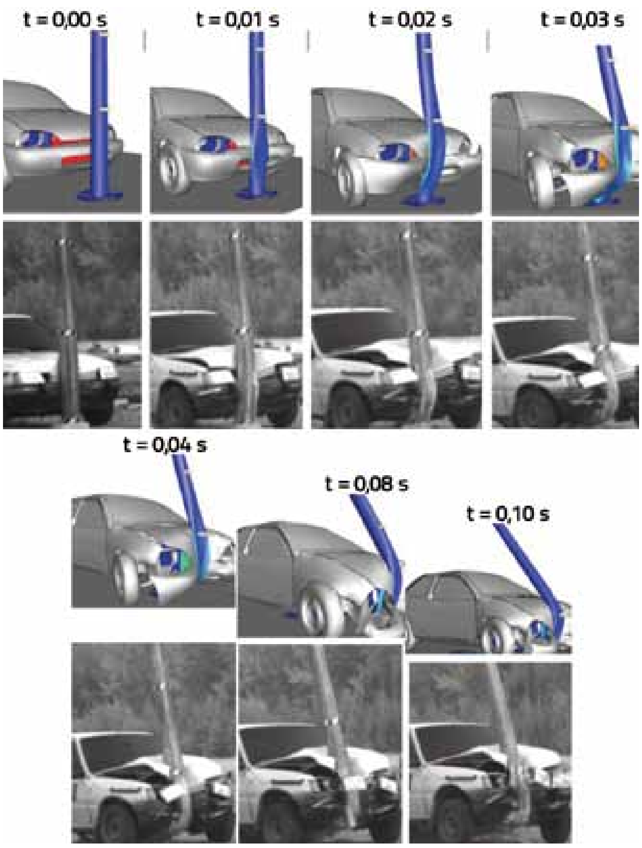

Figure 14. Behaviour of a composite column in a crash using numerical simulation and in actual practice

Figure 14 shows the behaviour of a composite column during a vehicle crash in the initial 0.1 seconds from the time of impact during the actual crash test and numerical simulation using the LS-DYNA computer program. It is evident that this type of column following a vehicle impact becomes more malleable, bends under the vehicle and subsequently absorbs energy.

Figure 15 shows an automobile having being stopped. It is evident that the vehicle crashing into such a column significantly reduces damage to the vehicle, while passenger safety increases more than in the case of a crash into a rigid column normally used along our roadways.

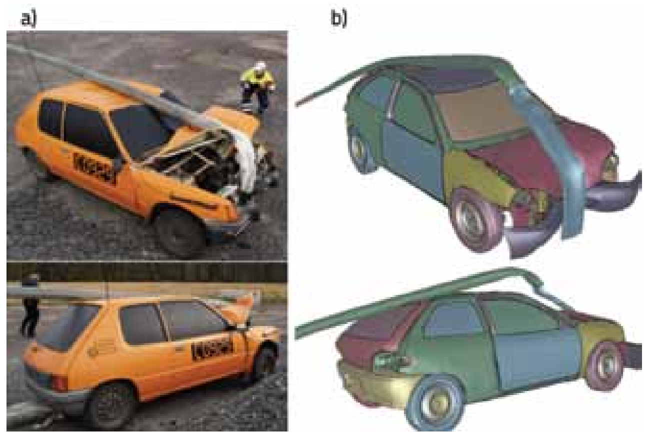

Figure 15. Vehicle being stopped [8]; a) crash test, b) numerical simulation

The company from Finland that presented the described composite columns providing controlled energy absorption in 2006 obtained an international award in Paris, where they were declared the best columns in the passively safe structure category complying to classification provided by the European standard EN 12767.

4.3. Low energy absorbing columns (LE columns)

Low energy absorbing columns (LE columns according to [5]) are a good combination of energy absorption and vehicle occupant safety since they possess certain qualities of high absorbing and non-absorbing columns. They have been designed to fail during a vehicle crash by yielding in front of and under the vehicle rather than shearing, as happens with non-absorbing columns. The behaviour of such columns during a vehicle crash is shown in Figure 16.

Figure 16. Behaviour of low energy absorbing columns [5]

The speed of a vehicle colliding into such a column will be reduced and damage to the vehicle is less than when colliding into a high absorbing column. On account of what has been said, columns that can absorb small amounts of energy are more suitable for use on ordinary roadways.
Figures 17 and 18 show a test crash with a class 100 LE 3 steel column at a vehicle speed of 35 km/h and 100 km/h [9].

Figure 17. Crash test at a speed of 35 km/h [9]; a) column and vehicle following collision, b) column following collision – column stopped the vehicle

Figure 18. Crash test at a speed of 100 km/h [9]; a) vehicle and column before collision, b) column after collision – vehicle speed reduced to about 60 km/h

5. Advantages and risks of using passively safe columns

The tribulation of people involved in traffic accidents poses a great emotional shock, not to mention huge expenses for society. Today, in Finland more than 90 % of new lighting columns are constructed so as to control breakage upon impact by a vehicle. These columns are somewhat more expensive than columns that are not passively safe.
Interesting enough is the approach taken to this problem in Belgium. According to data from the Belgium insurance company Assuralia, the cost for a seriously injured or fatality averages € 383,000 [10]. In 2007, in Belgium there were a total of 217 serious injuries or fatalities caused by vehicles colliding into lighting columns. If the number of victims is multiplied by damages amounting to € 383,000 per person, we arrive at a figure of € 83 million annually for medical assistance following traffic accidents involving vehicles colliding into lighting columns.

The main advantage in using passively safe columns compared to the traditional rigid columns is the less likelihood of serious injury to passengers in a vehicle that has collided into a column. By using columns that do not absorb energy (NE columns), greater safety for passengers in a vehicle following a collision is achieved where the vehicle continues to move at an appropriately reduced speed with less damage to the vehicle compared to other types of columns.
Columns that absorb energy significantly decelerate a vehicle and reduce the risk of a secondary collision with pedestrians, bicyclists and other participants in traffic. That is why they maintain an advantage on urban roadways where a significant number of non-motorised participants in traffic are present.
The use of passively safe columns is recommended for rural roads, especially where there is a problem preventing the installation of a protective barrier or in places where a protective barrier might cause traffic accidents, such as for instance on roundabouts. They are less required in places where protective barriers exist, or where there are house or rock faces very close to roads. Lighting columns and columns holding traffic signage on city roads are ordinarily protected by protective barriers, thereby reducing the potential likelihood of a vehicle colliding into a column. A vehicle colliding into a standard rigid column poses a very large risk for vehicle passengers and a small risk for other traffic participants. However, a vehicle colliding into a passively safe column poses a smaller risk to the vehicle occupants, but there is a small probability of the column falling onto the footpath or road, which may cause a secondary accident, thus posing a potential risk to other drivers and pedestrians close-by.
If the remainder of the column falls onto the carriageway, it is important how other drivers will react and how noticeable such remainders will be, for instance at night. However, in available literature, there is no information that debris from columns on roads cause problems in countries with a larger number of passively safe columns.
The risk posed to pedestrians is significantly greater in city rather than in urban areas. The risk depends on the number of pedestrians and exposed columns and therefore the recommendations from standard EN 12767 are that passively safe columns are not a good choice for locations where a large number of pedestrians are expected. In such cases, pedestrian safety must be taken into consideration since the risk of a vehicle that has lost control hitting a pedestrian may be greater than that posed by a falling column.

6. Recommendations by the European Commission

According to recommendations by the European Commission [3], all columns on new roads should be located within a safety zone. If this is not possible, only passively safe columns can be used. All columns must be tested in compliance to the valid EN 12767:2007 standard.

Until recently, in EU countries columns alongside motorways had to be placed behind a safety barrier. With changes to the law, now columns can be installed along motorways without protective barriers but under the condition that they have been tested and certified in compliance to standard EN 12767. The decision has been made that there is no need for protective barriers alongside motorways for class 100 NE 3 columns. These columns are non-energy absorbing and ensure the greatest protection for passengers in vehicle that has collided into a column.

Passively safe columns should be used on main roads where there is little likelihood of them falling onto carriageway or where only a small number of pedestrians are expected close-by. National Annex from Great Britain in regards to BS EN 12767 [11] for rural roads recommends the use of NE 100 columns, except if a significant number of pedestrians or bicyclists are expected to be close-by on account of the risk posed by a column falling onto the road. It is recommended that in city areas, class 70 LE or HE lighting columns and class 70 LE columns containing traffic signage be used.

Figure 19. An example of a break-away column [3]

Old rigid columns, and concrete or wooden lighting columns must be replaced with columns that can absorb energy in a controlled manner or break upon impact by a vehicle. Such columns can be made of steel, aluminium, wood or composite materials and and are recommended for places where pedestrian pathways are not close to the columns. Existing wooden and steel columns can be modified into those that break upon an impact by vehicle. Figure 19 shows an example of a possible modification to a rigid column.

7. Conclusion

Unfortunately, there will always be traffic accidents, but they can be reduced in numbers and seriousness. According to the recommendations of the European Commission, one of the ways in reducing the number and seriousness of traffic accidents is to use passively safe columns alongside roadways.

The use of columns that absorb energy or fail in a controlled manner achieves greater safety for drivers but which however poses a certain risk to pedestrians and other traffic participants due to the possibility of the column falling. Therefore, when choosing the type of column, it becomes necessary to consider each particular area, including the materials and manner that the columns fail, with the aim of reducing the degree of injuries to passengers in vehicles that have collided into a column, while at the same time taking into account pedestrians and other participants in traffic.

In order for the level of safety on road traffic to be improved, society would have to make continual improvements to roadside equipment. The final cost of investing into increased safety is less than the damage caused by accidents.

There are expectations that the positive experience and good results achieved through the use of passively safe columns in EU countries will encourage road traffic authorities in Croatia to introduce such columns.

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