Road restraint systems: unsung heroes of road safety

Martin Page
Convenor of CEN/TC 226 WG1 "Road Restraint Systems"

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Road Restraint Systems (RRS), often the last line of defence in protecting motorists in the event of a vehicle accidentally running off of the road, play a vital role in reducing fatalities and serious injuries on the Europe's roads. As the EU strives to achieve its "Vision Zero" goal of eliminating road deaths, investing in effective RRS along with updated standards and regulations remain essential for the ongoing improvement of road safety.

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Road safety: concerning trends behind the numbers

Figures published by the European Commission Directorate-General for Mobility and Transport show that, in 2024, nearly 20,000 lives were lost in road crashes across the EU – a 2% reduction with respect to the previous year. The Directorate General notes that while

these figures reflect steady progress towards the EU's Vision Zero objectives of halving fatalities and serious injuries by 2030 and getting close to eliminating them by 2050, the pace of improvement remains slow. Provisional data for the first semester of 2025 is reported to indicate mixed trends across EU member states leading the European Commission to highlight the need for "constant vigilance and sustained effort" in addressing road safety issues.

There are over four million kilometres of roads across the EU-27 countries and it is estimated that, on major European roads, each kilometre of road safety barrier is struck by an errant vehicle almost once every year. This highlights the vital role that road safety barriers, along with other types of RRS, play in saving lives and reducing injuries on the European road network.

Better safe than sorry: understanding road restraint systems and their impact on safety

Of course, the causes of serious and fatal injuries for road users are manifold, and the deployment of RRS is just one safety measure among many. Vehicles themselves are becoming safer, and roads are designed to guide drivers safely to their destination and to be "forgiving" of driving errors and accident-triggering events. However, despite the range of measures that help to keep vehicles on the road, run-off-road incidents are still frequent. Therefore, a variety of RRS exists to prevent errant vehicles from striking dangerous nearby obstacles or to mitigate the consequences of such a collision.

The most common RRS is the road safety barrier. These barrier systems are engineered to deliver various levels of performance under vehicle impact, ranging from lightweight, cost-effective models for lower-risk sites to high-performance, premium solutions for locations where the risk is greater.

Although barriers are essential for containing errant vehicles, impacting them can be dangerous for vehicle occupants. Therefore, when a barrier is necessary, the choice of model must take into account its containment capacity, its aggressiveness, and the space it requires to deform when struck by a vehicle. Insufficient clearance behind a barrier can compromise its performance and pose a hazard to pedestrians or nearby traffic.

To offer a wide range of performance options suited to each application, many different barrier models are available on the market, including steel, post and rail systems, precast or cast-in-place concrete barriers, wood-steel barriers, and modular steel barriers. For steel post and rail systems, variants with different strength and flexibility can be designed by adjusting, for example, the material thickness, post spacing and stiffness, or the number of horizontal rails. Concrete barriers offer a broad range of flexibility, from heavy systems fixed to the ground to lightweight, modular solutions that slide over the ground upon impact, effectively absorbing kinetic energy.

In addition to permanent barriers, temporary modular barriers (often called modular lane dividers) are widely deployed to protect work zones. These precast concrete or steel barriers offer a choice of characteristics allowing the selection of the most appropriate solution for each application.

Whilst safety barriers play a crucial role in reducing crash severity, their effectiveness at the beginning and end of an installation depends on properly designed end treatments. Untreated barrier ends can present significant dangers to the occupants of an impacting vehicle, such as exposing rigid elements that can be impacted or creating the risk of an impacting vehicle being impaled on the detached horizontal rail of the barrier. To prevent such outcomes, barrier ends—known as terminal sections—are typically flared away from the roadway, sloped toward the ground, or fitted with energy-absorbing terminals. The latter systems are engineered to decelerate impacting vehicles in a controlled manner, offering a more compact solution than other end treatments and reducing the likelihood of rollover or incidents of vehicles jumping over the barrier, which have been observed with turned-down ends.

Given the wide variety of safety barrier designs installed on European roads, many barrier transition systems are needed to maintain protection levels where different barrier models meet. To preserve the protection they offer, the two barriers must be connected in a way that avoids abrupt profile changes that can potentially be hazardous. Transitions allow for a smoother change of dimensions and properties between two barriers of different characteristics. These special RRS are engineered to maintain the performance of the connected systems whilst ensuring a gradually change from one barrier design to the other. Each transition must be specifically designed and evaluated for the two barriers to be joined.

Similarly, removable sections are designed to safely close openings in central reserve barriers. When closed, they ensure the same level of protection as the standard barrier section, whilst allowing quick opening when needed to put into place a contraflow, or for the passage of emergency vehicles.

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When isolated obstacles, such as toll booths or tunnel entrances, cannot be protected by barriers, crash cushions can offer an effective solution. These deformable devices absorb

the kinetic energy of an impact, reducing vehicle deceleration and thereby limiting the risk of injury to occupants. Available in various performance levels, they are selected on the basis of the types of impact considered and their energy absorption capacity. The truck-mounted attenuator (TMA) is a similar deformable system that is deployed mounted on a vehicle or trailer to protect mobile work zones from collisions with vehicles that fail to divert to an adjacent lane upstream of the work area.

In order to mitigate the risk of injury resulting from a motorcyclist striking the vertical posts of a steel guardrail having lost control of their vehicle, motorcycle protection systems (MPS) can be installed on barriers, providing a shield that prevents direct contact with these posts.

EN 1317 standard: cornerstone of road restraint system design and evaluation in Europe

The European standard EN 1317 defines how the performance of RRS is determined based on laboratory crash tests. Each system is designed to achieve a specific vehicle containment level, which in turn dictates the tests required to evaluate its performance. The test involves installing the test item in a specialist, accredited test centre (in the case of barriers, an appropriate length of installation is selected) and launching a road vehicle into it under conditions specified by the standard. The RRS being tested is installed on ground with characteristics similar to the intended installation site.

For barriers, up to three standardised crash tests are specified, with the vehicle typically impacting the barrier at a 20° angle and speeds of up to 110 km/h. The range of test vehicles specified includes three sizes of passenger car, weighing between 900 kg and 1,500 kg, four trucks ranging from 10 to 38 tonnes, and a 13-tonne bus.

The main objectives of the tests are to:

- Confirm the system's ability to adequately contain the vehicle identified for the intended containment level,
- Assess the severity of the impact for vehicle occupants,
- Measure the system's deformation during the crash.

Impact severity is usually assessed using the smallest passenger car (900 kg). The vehicle is equipped with sensors to measure deceleration and rotation, which are used to calculate occupant risk criteria.

Containment capacity is evaluated using a heavier car, a truck, or a bus, depending on the intended level of performance. For higher containment levels, an optional third test may be added using a 1,500 kg car to ensure the barrier performs adequately at an intermediate level.

All of the tests are filmed using several high-speed cameras, typically at a speed of 1,000 frames per second, in different positions so as to facilitate the analysis of the vehicle-RRS interaction.

Transitions and removable barrier sections are tested under conditions similar to those required for standard barrier sections. Crash cushions and barrier terminals are evaluated based on their behaviour during frontal, offset, and angled impacts. As a result, several tests are required so as to assess the effectiveness of the system in various configurations. Test specifications consider not only the system's ability to absorb impact energy, but also the vehicle's trajectory after the crash and the ensuing risk of secondary collisions.

Since the first publication of EN 1317 in 1998, thousands of tests have been conducted across Europe and further afield. The adoption of a universal performance characterisation on the basis of a standardised test method has facilitated access to European markets and beyond, and stimulated innovation in the field. The introduction of CE marking in 2013 for barriers and crash cushions further strengthened this dynamic by offering a common certification, further simplifying access to different markets.

It is important to note that the performance determined by EN 1317 tests is only an evaluation of the system's capabilities under standardised conditions. This benchmark performance enables product comparison and simplifies RRS specification in procurement processes. However, the tests cannot fully guarantee vehicle containment in every real-world accident, as actual crashes rarely replicate the exact parameters of EN 1317 tests.

Moreover, it is crucial to ensure that systems are installed on the same type of ground as those used in the tests, in order to achieve the full system performance identified with the testing. Ground conditions can significantly influence crash performance. Given the site-to-site variability of soil characteristics, it is impractical to test each RRS on every ground type. Therefore, it is essential to ensure that on-site ground characteristics will allow full performance to be attained, or to apply local adaptations to address any discrepancies.

Paving the way forward

Despite recent and on-going technological advances in road vehicle collision avoidance systems, RRS remain an indispensable element of road infrastructure. It is therefore essential to continue efforts to innovate in the field and to improve and update the EN 1317 standard, building on the progress already made in road safety.

Disparity in performance requirements between countries

In line with the approach of the EU's Construction Products Regulation (CPR), EN 1317 primarily aims to identify the product "type" for each RRS, i.e. classify RRS according to their performance under impact. The selection of performance levels for each category of road and for different sites on the road network remains the responsibility of national authorities.

A summary of minimum national requirements for barrier performance on motorways in the EU, Norway, and the United Kingdom was published in 2012 by the European Union Road Federation (ERF) — and remains largely relevant today (*see Table below*).

The EN 1317 containment levels for barriers, in ascending order of performance, are:

- T1 to T3 (low levels of containment – mainly for temporary barriers).
- N1 and N2 (normal containment).
- H1 to H4a/b (high containment), or L1 to L4a/b (H level + test with 1,500 kg car).

Country	Hard Shoulder	Central Reserve	Bridge
Austria	H2	H3	H3
Belgium	H2	H2	H4b
Bulgaria	H1	H2	H1
Czech Republic	H1	H2	H1
Denmark	H1	H2	H3
Finland	N2	N2	H2
France	N2	H1	H2
Germany	H1	H2	H1
Ireland	N2	H2	H2
Italy	H2	H3	H4b
Netherlands	H2	H2	H2
Norway	N2	H2	H2
Poland	H1	H2	H1
Spain	N2	H1	H3
United Kingdom	N2	H1	H1

National minimum requirements for motorways in 2012 © ERF

It is evident that RRS requirements vary significantly between countries, with the highest containment levels rarely adopted. While higher containment levels are, logically, reserved for high-risk areas, the criteria remain highly heterogeneous across nations. For example, minimum requirements span three levels for hard shoulders and four levels for bridges.

The ever-broadening range of available RRS options offers national authorities an opportunity to enhance safety by gradually adopting higher performance levels.

The use of the EN 1317 standard, along with the associated CE marking for barriers and crash cushions, has led to the development of more effective RRS and a greater diversity of available solutions. Some parts of EN 1317 have been revised over the years, particularly parts 2 and 3 covering road safety barriers and crash cushions. These parts of the standard were last updated in 2010 after eleven years of use. However, a major revision completed in 2019 could not be published due to the pending update of the CPR.

EN 1317 and the evolving European road vehicle fleet

With the growing momentum of electric vehicles in Europe, there is a need to take into account RRS performance against this type of vehicle. Their low chassis, made possible by compact powertrains, raises questions about the risk of the vehicle front end becoming wedged under the barrier rail resulting in a change to the vehicle-barrier interaction, potentially resulting in an altered performance or failure to contain the vehicle. This evolution could justify a future revision of the standard, provided it is based relevant statistical studies and on robust test data. Experimental results are beginning to emerge, and further studies will help understand what changes might be needed in the standard to adequately take into account such vehicles.

The increasing size of European cars, combined with increasing equipment and the weight of electric vehicle batteries, resulted in a gradual rise in the weight of passenger cars. Yet, the current standard only considers cars weighing up to 1,500 kg, while heavier models are becoming increasingly common. An increase in passenger car weight, or the addition of heavier vehicles to the standard, has long been under consideration. However, the context of the CPR revision is preventing any update to the relevant parts of EN 1317 before the early 2030s at the earliest.

While adapting the standard to heavier vehicles is a valid consideration, revising national requirements for the performance levels of deployed RRS could offer a more immediate and effective path to improving road safety. For example, containment level N2 (1,500 kg car) is commonly required for hard shoulder barrier applications. Yet, a level L1 barrier (one level higher than N2) — tested with a 10-tonne truck — is likely to be better suited to containing not only heavier passenger cars but also the increasingly prevalent SUVs and light commercial vehicles currently absent from the standard. Of course, raising the bar in this way might result in an associated increase in cost. This being said, due to improving barrier design over the years, an increase in performance class no longer necessarily represents a significant increase in cost. Furthermore, increasing test vehicle weight in the standard

would lead to a need for additional product testing on the basis of the revised standard and, in all probability, additional RRS development costs, whilst no effects would be seen on roads for years to come due to the timeline of updating the standard, developing new products and testing them. In contrast, transitioning to higher performing RRS already available on the market is an alternative solution allowing the increasingly heavy passenger car fleet to be taken into account with immediate effect and with the added benefit of increasing the range of vehicle types and sizes safely contained.

In the current standard, impact severity is assessed using the lightest specified vehicle: the 900 kg passenger car. This vehicle is used to represent a "worst case" scenario since lighter cars tend to experience greater impact decelerations due to their limited ability to absorb energy through structural deformation. Although the average weight of city cars has increased in recent years, some variants of popular models — such as the Renault Twingo or Suzuki Swift — still weigh less than 1,000 kg. Even if cars under 1,000 kg represent a small portion of today's vehicle fleet, it remains essential to retain this category in the standard for the future. Any future initiative to increase the weight of the light car test vehicle due to shifting trends in the vehicle fleet should not preclude the possibility of a return to the 900 kg category should vehicle weights fall once more in the future.

As for heavy vehicles, the standard currently specifies a 13-tonne bus for testing H2/L2-level barriers, which was representative of vehicles at the time of writing the standard. However, modern coaches can weigh up to 18 tonnes when loaded, or even 25 tonnes for three-axle models. This evolution raises questions about the relevance of testing with a 13-tonne bus. However, it is important to note that EN 1317 does not specifically assess a barrier's ability to contain a bus. The test is primarily intended to evaluate the barrier's capacity to contain a 13-tonne vehicle, with the bus serving as a typical representative of that weight category.

When heavier vehicles need to be considered — whether coaches or others — higher performance levels (H3, H4a, H4b) are already defined in the standard, and barriers tested to these levels are available on the market. As with N2 barriers, using higher containment level barriers is a readily available solution for planners wishing to account for heavy coach traffic. This approach is particularly relevant for bridge parapet barriers, often classified as H2 and thus tested with a 13-tonne bus. Whilst real-world crash conditions do not necessarily match exactly the standardised test scenarios, the fact remains that many barriers installed in sensitive locations are not designed to contain vehicles exceeding 13 tonnes — unless the real-world impact is less severe than the test conditions.

Reconciling safety and carbon footprint

As sustainability becomes a central pillar of infrastructure policy, driven by initiatives such as the European Green Deal, RRS will be assessed not only on their performance in the event of a vehicle impact, but also on their carbon footprint. This change raises a complex challenge: reconciling environmental responsibility and road safety without compromising safety. The use of materials with a low carbon footprint would be likely to increase the cost

of the systems. However, in a context of often constrained budgets, price is already a determining criterion in the selection of RRS. Life cycle assessments show that RRS raw materials are the main contributors to their carbon footprint. It is, therefore, highly likely that carbon footprint reduction constraints will encourage manufacturers to reduce the quantities of materials to the strict minimum necessary to achieve the required performance. This approach could result in the erosion of safety margins, making RRS less able to effectively contain vehicles in real-world crash scenarios that deviate from test conditions. In this context, it is essential that efforts to reduce carbon emissions are carried out without lowering safety levels. While any increase in the required performance levels of RRS can lead to an increase in the carbon footprint per unit or linear metre due to the increased use of materials, this trade-off must be put into perspective with the road safety gains it enables. It should be noted that whilst the contribution of RRS to the total carbon footprint of a road project is relatively minor, reducing the quantity of materials used in an RRS can have a significant detrimental impact on the performance safety margins of an RRS. An effective strategy is to favour RRS with a long service life, thus limiting the replacement of the installation over the years. This reduces the environmental impact while maintaining a high level of safety.

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The rise of virtual testing techniques

Given the high cost of crash testing, numerical simulation techniques have become an invaluable tool in the development of RRS. Computer simulation allows so-called virtual tests to be performed based on detailed numerical models of RRS and vehicles. Although simulations are not a substitute for physical testing, they are a powerful complementary tool provided that the RRS models are validated against physical reference crash tests, i.e. the virtual tests faithfully reproduce the results of the physical crash tests. Once validated, a model allows reliable, additional virtual testing to be performed on a wide range of

additional test configurations or product variants at a lower cost than carrying out additional physical crash tests.

Virtual testing is now widely used alongside EN 1317 to evaluate modifications to products that are already certified and to explore alternative impact scenarios in addition to the EN 1317 test conditions. European standard EN 16303 provides the framework to ensure the quality and consistency of this RRS modelling. However, to ensure the credibility of virtual testing, it is essential to ensure that the model has been correctly validated and that rigorous transparency is employed. Furthermore, when virtual testing studies are considered as part of the evaluation process when a certified product is modified, they must be reviewed by a competent and independent expert to ensure objectivity and reliability.

A striking example of the effective use of virtual testing is the evaluation of transitions between different safety barriers. These transitions must be tested connected to the same two barriers that they are designed to join. In addition, several tests are required with different points of impact. As a result, many different transitions are needed to connect all possible barrier combinations, with several tests performed on each system. In many cases, once the first tests have been performed physically, the remaining impacts can be performed virtually at a reduced cost and without the need for organising the tests at a laboratory and providing additional hardware for the evaluation.

Since, in the past, a proposal to formally integrate virtual tests into EN 1317 for the evaluation of transitions was found to be incompatible with the CPR, transitions are currently evaluated on the basis of the individual national requirements of different countries. However, some countries, in particular France with its national NF058 standard, have very successfully adopted a national approval approach combining physical and virtual testing in appropriate cases.

In the future, a more harmonised European approach to the use of virtual testing for RRS assessment would offer significant benefits especially for complex systems such as transitions. By increasing the adoption of validated virtual testing as a complement to physical crash testing in product evaluation, certification costs can be minimized while driving innovation.

Conclusion

Despite a long-term reduction in the number of road traffic fatalities in Europe, the accident statistics remain concerning. Road Restraint Systems, evaluated according to the EN 1317 standard since 1998, play a key role in protecting road users. Even with advances in active safety technologies and autonomous vehicles, RRS remain essential to reducing the number of casualties. In spite of past efforts to update EN 1317, further work remains constrained by the EU regulatory framework meaning that a full revision cannot be undertaken for several years. In the meantime, one way to address the evolving European vehicle fleet is to specify higher-performing RRS for Europe's roads.

Key points

- Road restraint systems are essential for protecting road users.
- The European standard EN 1317 plays a key role in evaluating RRS performance.
- The evolution of the European vehicle fleet should be considered in future updates of RRS standards and in RRS deployment practices.
- Numerical simulation is a valuable complementary tool for the development, optimization, and certification of RRS.
- The carbon footprint of RRS is becoming an important criterion, but environmental requirements must not compromise road safety.