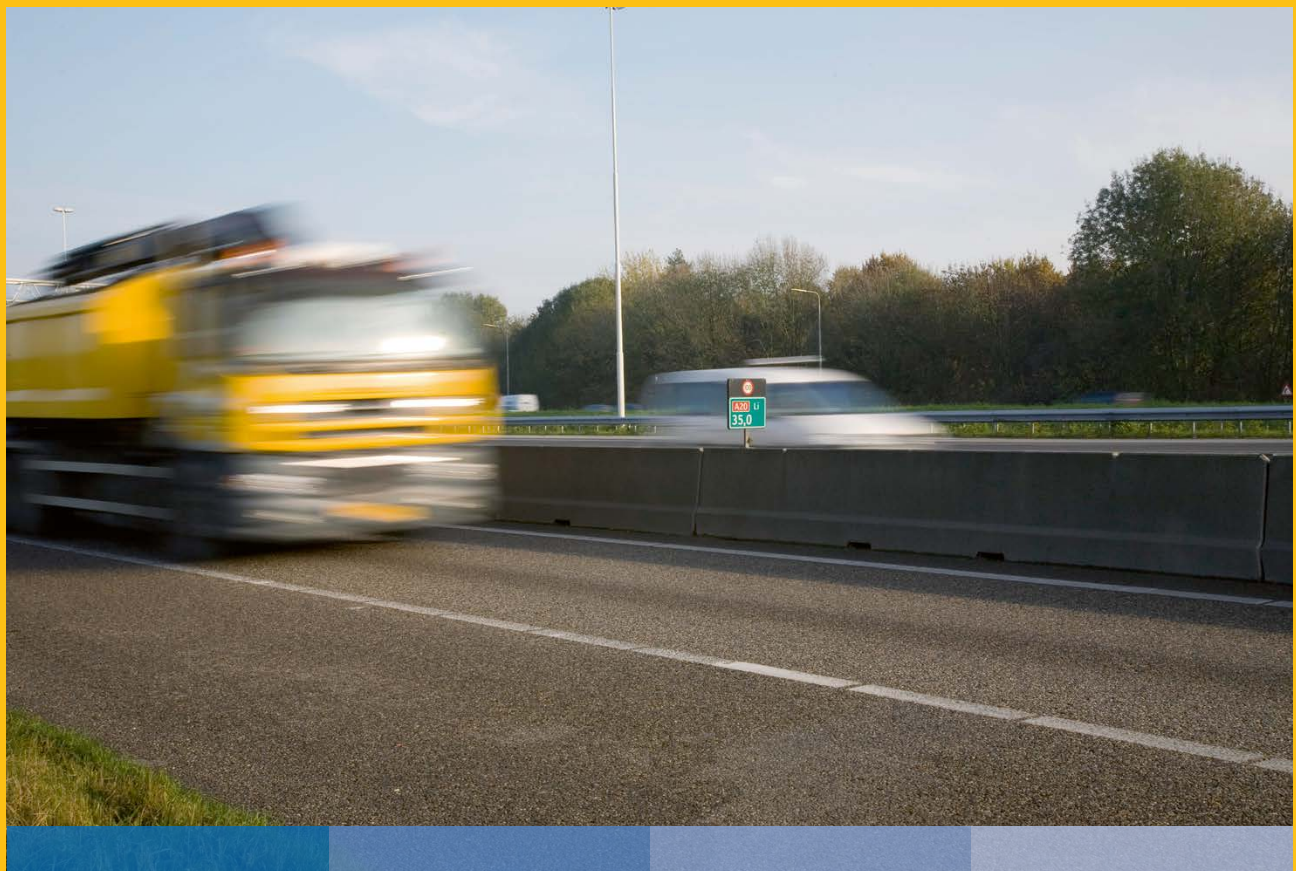
Concrete safety barriers: a safe and sustainable choice

Photo: Gomaco

CONTENTS

Photo: M. Van Kerckhoven



1. INTRODUCTION

One of the top ten goals set by the White Paper on Transport (2011) is to reduce fatalities in road transport. The increase of the safety of the road infrastructure had been one of the seven main aims of the policy orientations made by the European Commission (EC) regarding to road safety for 2011-2020.

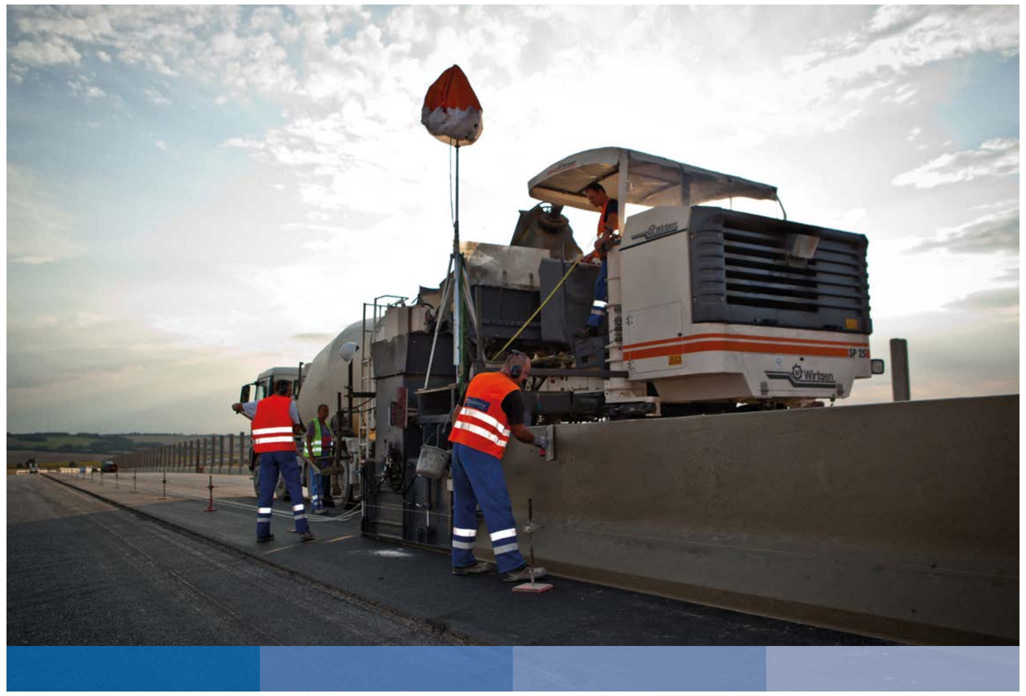
From 2010 to 2016, the number of road fatalities in the EU decreased from 31.500 – the equivalent of a medium town- to 25.500. This represents a 19% reduction over the last six years.

However, despite of the fact that the EU has the safest roads in the world, 70 people are still dying and 370 got serious injuries every day. These figures are insufficient if the EU wants to meet its target of halving road fatalities between 2010 and 2020 (only 40 people by 2020). The European Commission also settled as a long-term goal to move close to zero road fatalities by 2050.

Car occupants account for the largest share of victims (46%). Motorcyclists, who are less protected during a crash, account for 14% of road fatalities. Put together, vulnerable road users, including pedestrians, cyclists and motorcyclists account for the same proportion and are particularly exposed in urban areas.

One of the ways to achieve this goal, amongst others such as intelligent vehicles and better enforcement, is safer road infrastructure. The use of passive safety systems and, more specifically, road restraint systems undoubtedly contributes to higher safety. There will also be more focus on vulnerable road users, motorcyclists in particular. [Ref. 8]

Photo: Deltabloc



2. BENEFITS OF CONCRETE SAFETY BARRIERS

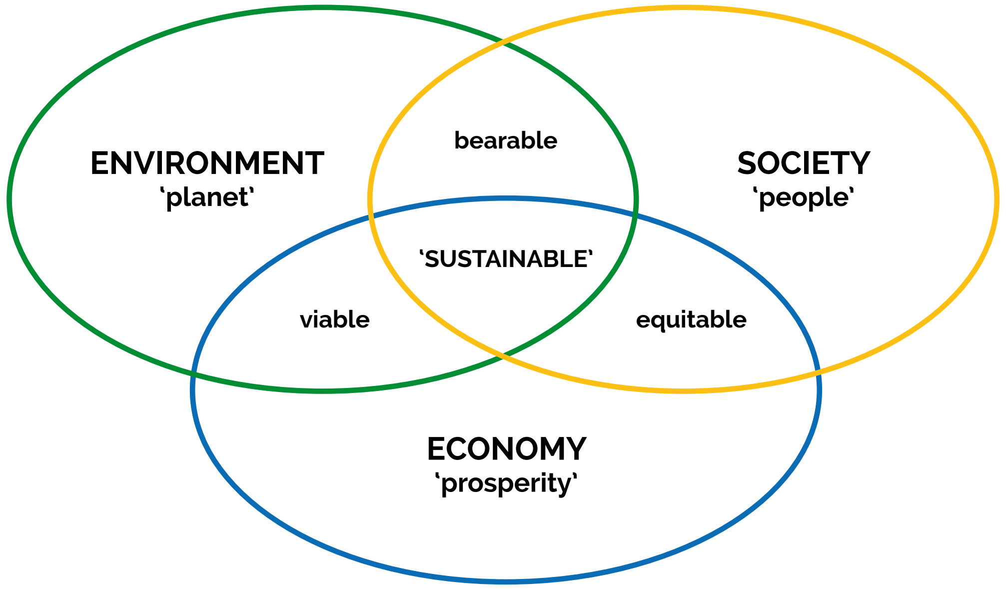
Another concern of the EC is the use of sustainable solutions, fitting in the concept of Green Public Procurement. Concrete safety barriers give answers to both the issues of road safety and sustainability. The figure below lists the benefits of concrete safety barriers in the three domains of sustainable construction: environment, economy and society. These statements will further be discussed in this publication.

> ENVIRONMENT

- 80% less embodied CO_2 than steel systems
- Minimum material usage and waste
- Non polluting in service
- 100% recyclable
- Virtually maintenance-free over their 50-year design life
- Reduce traffic congestion and associated emissions

> SOCIETY

- Increasing safety for road user and worker
- No break-through of collision vehicle
- Low maintenance increases road availability and reduces traffic congestion
- Safe solution for motorcyclists



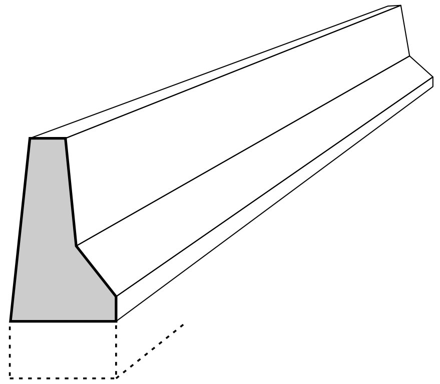
> ECONOMIC FACTORS

- Very long design life
- Minimum space required
- Almost maintenance-free
- Remain functional even after severe collisions
- High daily production of 400 to 800 m possible
- Temporary systems available for road works

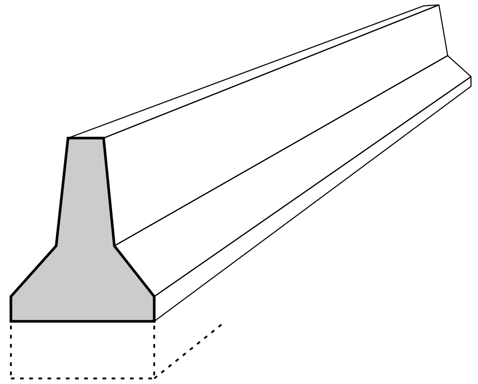
3. HISTORY OF CONCRETE SAFETY BARRIERS IN EUROPE

Since the 1970s, the central reserves of highways and motorways in Europe have been protected with (steel) guardrail structures. The necessary maintenance on the road due to damages from accidents led to congestion, especially at narrow road sections. This raised the question of how to develop other types of roadside safety structures.

Figure 1 Versions of the old New Jersey barrier



One-sided version that was used in wider central reserves and roadsides



Double-sided version, for (very narrow) central reserves

NEW JERSEY PROFILE

The need for durable construction with minimal maintenance and without unacceptable reduction in safety soon arose. The concrete safety barrier with what is known as a New Jersey profile fitted these requirements. This type of barrier was originally designed in America by General Motors in 1955 and first used in New Jersey. The first applications in Europe were found in Belgium and France from the 1970s onwards. [Ref. 4]

The New Jersey profile in Europe was more or less standardised in two versions:

CONCRETE STEP BARRIER (CSB)

Rijkswaterstaat, the Dutch Road Administration, explored other barrier profiles. In the 1990s they developed in the Netherlands the "embedded step" profile, based upon the English "single-slope" barrier. [Ref. 4]

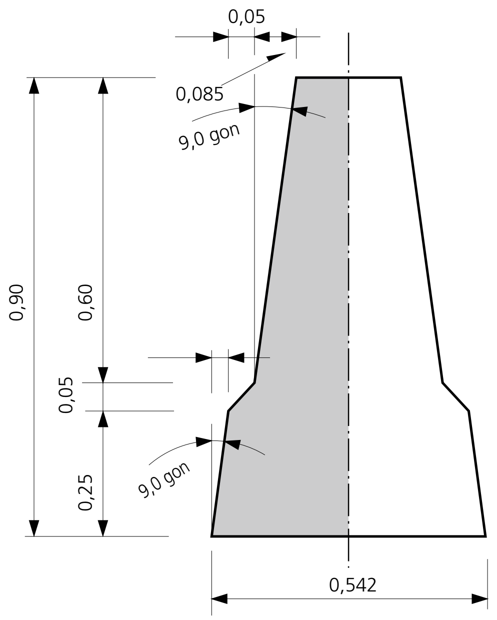
New Jersey barrier in the central reserve of a motorway

Photo: W. Kramer

One of the first applications of the concrete step barrier on motorway E429 in Belgium (1999)

Photo: P. Van Audenhove

Figure 2 Standard geometry of the concrete step barrier



DEVELOPMENT OF NEW TYPES OF IN SITU CAST CONCRETE SAFETY BARRIERS

For a long time, mainly between 2000 and 2010, the step barrier was the most used type of in situ cast concrete safety barrier in Europe. After 2010, following the revised version of the European standards EN1317-1 and -2, new types have been developed, mostly improved versions of the new jersey profile.

Photos: left:Givasa
right: Deltabloc International

IN SITU CAST AND PRECAST CONCRETE SAFETYBARRIER

A concrete barrier can either be cast in situ or be precast in a production unit.

The in situ installation is done by means of a slipform paver using ready mixed concrete. This kind of installation allows very high daily production rates and consequently competitive prices. The barrier can be tied to the substructure (a cement treated or asphalt base layer) or can be surface mounted without any anchoring.

Prefabricated elements are manufactured in an indoor environment and assembled on the worksite, making their installation less dependent on climatic conditions. Since they can easily be displaced, they are very often used for protection of the work site during road construction.

Surface mounted CSB installation

Photo: BAM Wegen

Photo: L. Rens

Precast barriers in a permanent and a temporary installation

Photo: Omnibeton – Deltabloc

4. THE EUROPEAN STANDARDS: EN 1317

In the beginning of the 1990s, CEN, the European Committee for Standardisation, set up a Technical Committee on road equipment (CEN/TC 226) and a working group (WG 1), dedicated to the drafting of standardised rules for different types of road restraint systems. The initial and revised versions, including amendments, of the European standards of the EN 1317 series are the following (status February 2018):

EN 1317-1:1998 EN 1317-1:2010 (revision)	Terminology and general criteria for test methods
EN 1317-2:1998 + A1:2006 EN 1317-2:2010 (revision)	Performance classes, impact test acceptance criteria and test methods for safety barriers including vehicle parapets
EN 1317-3:2000 EN 1317-3:2010 (revision)	Performance classes, impact test acceptance criteria and test methods for crash cushions
ENV 1317-4:2001	Performance classes, impact test acceptance criteria and test methods for terminals and transitions of safety barriers
EN 1317-5:2007 + A2:2012	Product requirements and evaluation of conformity for vehicle restraint systems
CEN/TR 1317-6:2012	Pedestrian restraint systems – Pedestrian parapets
CEN/TS 1317-8:2012	Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers
CEN/TR 16303-1 to 4:2012	Road restraint systems – Guidelines for computational mechanics of crash testing against vehicle restraint system

The following normative documents are in phase of preparation (status February 2018):

prCEN/TR xxxx	Road restraint system — Assessment methods and design guidelines for transitions — Complementary element
prEN 1317-5	Road restraint systems - Part 5: Product requirements, test and assessment methods and acceptance criteria
prCEN/TR xxxx	Road restraint system — Assessment methods and design guidelines for transitions and terminal connections

Notes:

- crash cushions and pedestrian restraint systems will not be dealt with in this publication;
- EN = European standard, approved
- A = Amendment
- ENV = Pre-standard
- TS = Technical specification
- TR = Technical report
- pr = project, in state of preparation, not yet approved

5. PERFORMANCE AND TEST METHODS FOR VEHICLE RESTRAINT SYSTEMS

PERFORMANCE CLASSES – CONTAINMENT LEVELS

The first version of the European standard EN 1317-2 was published in 1998. A revised version was published in 2010. The original version defined 10 performance classes. The higher the performance level, the stronger the construction needs to be in order to withstand higher impact demands. Each performance class refers to a number of crash tests. A road restraint system, allocated to a specific class, must be able to retain the specified vehicles at determined speeds and impact angles. Table 1 gives an overview of the different standardised crash tests.

The low angle containment levels are intended to be used only for temporary safety barriers. However, temporary safety barriers can also be tested for higher levels of containment.

A successfully tested barrier at a given containment level should be considered as having met the containment requirements of any lower level, except that N1 and N2 do not include T3. This is because level T3 includes a test with a rigid truck (TB41) while for levels N1 and N2 only crash tests with cars are provided.

The very high containment levels H4a and H4b should not be regarded as equivalent and no hierarchy is given between them. The difference in tests TB71 with a rigid truck and TB81 with an articulated truck originates from the use of significantly different types of heavy vehicles in different countries.

TABLE 1 STANDARDISED CRASH TESTS

Test	Type of vehicle	Mass (kg)	Speed (km/h)	Impact angle (°)
TB11	car	900	100	20
TB21	car	1300	80	8
TB22	car	1300	80	15
TB31	car	1500	80	20
TB32	car	1500	110	20
TB41	rigid truck	10000	70	8
TB42	rigid truck	10000	70	15
TB51	bus	13000	70	20
TB61	rigid truck	16000	80	20
TB71	rigid truck	30000	65	20
TB81	articulated truck	38000	65	20

The following containment levels are defined (EN 1317-2:1998):

- low angle containment: containment levels T1,T2 and T3;
- normal containment: containment levels N1 and N2;
- high containment: containment levels H1,H2 and H3;
- very high containment: containment levels H4a and H4b.

Example of a precast barrier with very high containment level (H4b) on a viaduct

Photo: Deltabloc

Table 2 gives an overview of the different containment levels.

Since the revision of the standards EN 1317, parts 1, 2 and 3, in 2010, new containment levels "L" have been added to the classes of high and very high containment. The performance of the "L" classes is enhanced in respect to the corresponding H classes by the addition of test TB32 with a 1500-kg car.

ASI (ACCELERATION SEVERITY INDEX)

The index ASI is intended to give a measure of the severity of the motion for a person within a vehicle during an impact with a road restraint system. It is measured and calculated as the resultant of the decelerations in different directions of a fixed point of the vehicle, close to the centre of mass. The higher the ASI index, the more severe the collision, in general.

TABLE 2 CONTAINMENT LEVELS IN EN 1317-2:2010

Containment levels				Acceptance test
Low angle containment	T1			TB 21 TB 22
	T2			
		T3		TB 41 and TB 21
Normal containment	N1			TB 31
	N2			TB 32 and TB 11
Higher containment		H1		TB 42 and TB 11
			L1	TB 42 and TB 32 and TB 11
		H2		TB 51 and TB 11
			L2	TB 51 and TB 32 and TB 11
		H3		TB 61 and TB 11
			L3	TB 61 and TB 32 and TB 11
Very high containment		H4a H4b		TB 71 and TB 11 TB 81 and TB 11
			L4a L4b	TB 71 and TB 32 and TB 11 TB 81 and TB 32 and TB 11

THIV (THEORETICAL HEAD IMPACT VELOCITY)

THIV was developed for assessing occupant impact severity for vehicles involved in road collisions with road vehicle restraint systems. The occupant is considered to be a freely moving object (head) that, as the vehicle changes its speed during contact with the vehicle restraint system, continues moving until it strikes a surface within the interior of the vehicle. The magnitude of the velocity of the theoretical head impact is considered to be a measure of the severity of the impact of the vehicle to the vehicle restraint system.

IMPACT SEVERITY LEVELS

The evaluation of the impact severity indices is carried out for cars (for the higher and very high containment levels, the considered test is TB11 and in case of the L classes, additionally test TB32). The severity level is determined by the highest value from the tests.

Table 3 gives the subdivision in three impact severity classes A, B and C. For each of these classes, a maximum for the ASI value is specified together with a maximum for the THIV value, which is the same for the three classes (33 km/h). Impact severity level A affords a greater level of safety for the occupant of a car involved in a collision than level B, and level B a greater level than C.

TABLE 3 IMPACT SEVERITY CLASSES IN EN 1317-2:2010 (AFTER REVISION)

Impact severity class	ASI		THIV	Impact angle (°)
A	≤ 1,0	and	≤ 33 km/h	20
B	≤ 1,4	and	≤ 33 km/h	8
C	≤ 1,9	and	≤ 33 km/h	15

DEFORMATION OF THE RESTRAINT SYSTEM

The deformation of safety barriers during impact tests is characterised by the dynamic deflection, working width and vehicle intrusion.

The dynamic deflection (D_m) shall be the maximum lateral dynamic displacement of any point of the traffic face of the restraint system (see figure 4).

Photo: L. Rens

The working width (W_m) is the maximum lateral distance between any part of the barrier on the undeformed traffic side and the maximum dynamic position of any part of the barrier. If the vehicle body deforms around the vehicle restraint system so that the latter cannot be used for the purpose of measuring the working width, the maximum lateral position of any part of the vehicle shall be taken as an alternative (see figure 4).

The vehicle intrusion (VI_m) of a Heavy Goods Vehicle (HGV) is its maximum dynamic lateral position from the undeformed traffic side of the barrier (see figure 4). It shall be evaluated from high speed photographic or video recordings.

The dynamic deflection, the working width and the vehicle intrusion allow determination of the conditions for installation of each safety barrier and also to define the distances to be provided in front of obstacles to permit the system to perform satisfactorily.

EN 1317-2:2010 provides formulas to turn the measured figures D_m, W_m and VI_m into normalised values D_N, W_N and VI_N. For W_N and VI_N, classes of different levels are defined in EN 1317-2:2010 (see tables 4 and 5).

Photo: www.gva.be

TABLE 4: CLASSES OF NORMALISED WORKING WIDTH LEVELS (EN 1317-2:2010)

Classes	Levels of normalised working width
W1	$W_N \leq 0{,}6$ m
W2	$W_N \leq 0{,}8$ m
W3	$W_N \leq 1{,}0$ m
W4	$W_N \leq 1{,}3$ m
W5	$W_N \leq 1{,}7$ m
W6	$W_N \leq 2{,}1$ m
W7	$W_N \leq 2{,}5$ m
W8	$W_N \leq 3{,}5$ m

In specific cases, e.g. when there is limited space between the vehicle restraint system and an obstacle, a class of working width less than W1 may be specified.

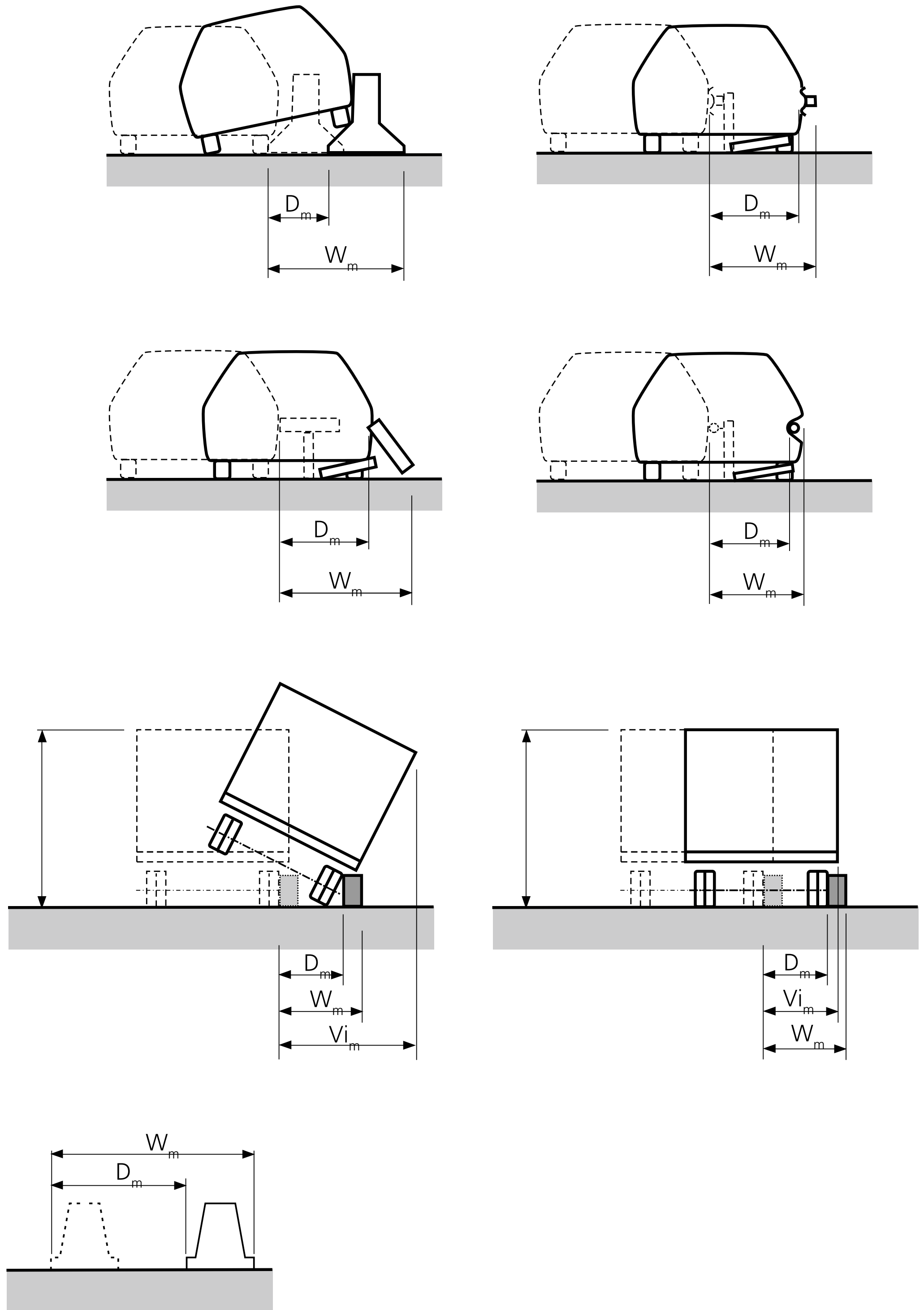
TABLE 5: CLASSES OF NORMALISED VEHICLE INTRUSION (EN 1317-2:2010)

Classes	Levels of normalised vehicle intrusion
VI1	$VI_N \leq 0{,}6$ m
VI2	$VI_N \leq 0{,}8$ m
VI3	$VI_N \leq 1{,}0$ m
VI4	$VI_N \leq 1{,}3$ m
VI5	$VI_N \leq 1{,}7$ m
VI6	$VI_N \leq 2{,}1$ m
VI7	$VI_N \leq 2{,}5$ m
VI8	$VI_N \leq 3{,}5$ m

In specific cases, a class of vehicle intrusion less than VI1 may be specified.

Dynamic deflection, working width and vehicle intrusion are important parameters in defining the distance that should be allowed between the barrier and an obstacle such as lighting posts.

Figure 4 Dynamic Deflection (D_m), Working Width (W_m) and Vehicle Intrusion (VI_m) - measured values



IMPACT TEST ACCEPTANCE CRITERIA

The test parameters on which acceptance criteria shall be assessed are listed in table 6 as a function of the containment level.

TABLE 6: TEST CRITERIA PER CONTAINMENT LEVEL

Containment level	PARAMETERS			
	Safety barrier including parapet and vehicle behavior	Impact severity level ASI-THIV	Vehicle deformation (VCDI)	Safety barrier including parapet deformation
T1 T2 T3	TB 21 TB 22 TB 41 + TB 21	TB 21 TB 22 TB 21	TB 21 TB 22 TB 21	TB 21 TB 22 TB 41 + TB 21
N1 N2	TB 31 TB 32 + TB 11	TB 31 TB 32 + TB 11[a]	TB 31 TB 32 + TB 11	TB 31 TB 32 + TB 11
H1 H2 H3	TB 42 + TB 11 TB 51 + TB 11 TB 61 + TB 11	TB 11 TB 11 TB 11	TB 11 TB 11 TB 11	TB 42 + TB 11 TB 51 + TB 11 TB 61 + TB 11
H4a H4b	TB 71 + TB 11 TB 81 + TB 11	TB 11 TB 11	TB 11 TB 11	TB 71 + TB 11 TB 81 + TB 11
L1 L2 L3	TB 42 + TB 32 + TB 11 TB 51 + TB 32 + TB 11 TB 61 + TB 32 + TB 11	TB 32 + TB 11a TB 32 + TB 11a TB 32 + TB 11a	TB 32 + TB 11 TB 32 + TB 11 TB 32 + TB 11	TB 42 + TB 32 + TB 11 TB 51 + TB 32 + TB 11 TB 61 + TB 32 + TB 11
L4a L4b	TB 71 + TB 32 + TB 11 TB 81 + TB 32 + TB 11	TB 32 + TB 11a TB 32 + TB 11a	TB 32 + TB 11 TB 32 + TB 11	TB 71 + TB 32 + TB 11 TB 81 + TB 32 + TB 11
NOTE: VCDI is not an acceptance criterion.				
[a] : The severity level is determined by the highest value from the tests, all results to be included in the test report.				

PERFORMANCES OF IN SITU CAST CONCRETE SAFETY BARRIERS
As already stated, the concrete step barrier was for a long time the standard solution for in situ cast concrete vehicle restraint systems in Europe. The original tests, performed in 1995, resulted in the following performances:

Containment level...............**H2**
Working width......................**W2**
Impact severity class............**B**

In the meantime several variants of this solution have been developed, tested and adopted (free standing instead of restrained, different heights and/or widths etc.), mainly in Germany and the UK.
Since 2010, other types of in situ cast concrete safety barriers have been developed, most of them with the characteristics **H1 to H3 – W1 to W4 – B**, all of them CE-marked.

6. TERMINALS, TRANSITIONS AND REMOVABLE BARRIER SECTIONS

Terminals are defined as the beginning and/or end treatment of a safety barrier. They are required to have specified impact performances without introducing additional hazards for passenger cars.

Problems may also arise in the connection between two different safety barriers having consistent difference in design and/or in stiffness. Transitions are required to provide a smooth and safe change from one barrier to another.

A removable barrier section is defined as a section of barrier connected to a barrier at both ends which allows for removal and reinstallation for temporary openings. These are mainly used for emergency reasons or maintenance access, and which, in closed position, offer appropriate containment performances.

ENV 1317-4 covers performance classes and test methods for terminals and transitions. Several systems have been tested and approved to conform with ENV 1317-4 for transitions between different concrete safety barriers (precast-to-precast, in-situ-to-in-situ, precast-to-in-situ) or between concrete and steel barriers.

Currently it is proposed to split the pre-standard ENV 1317-4 into two Technical Reports (CEN/TR).

Examples of transitions between different concrete vehicle restraint systems

Photo: Deltabloc

Photo: L. Rens

Transition between a concrete step barrier and a steel system

Photo: Linetech

7. CE MARKING OF CONCRETE SAFETY BARRIERS

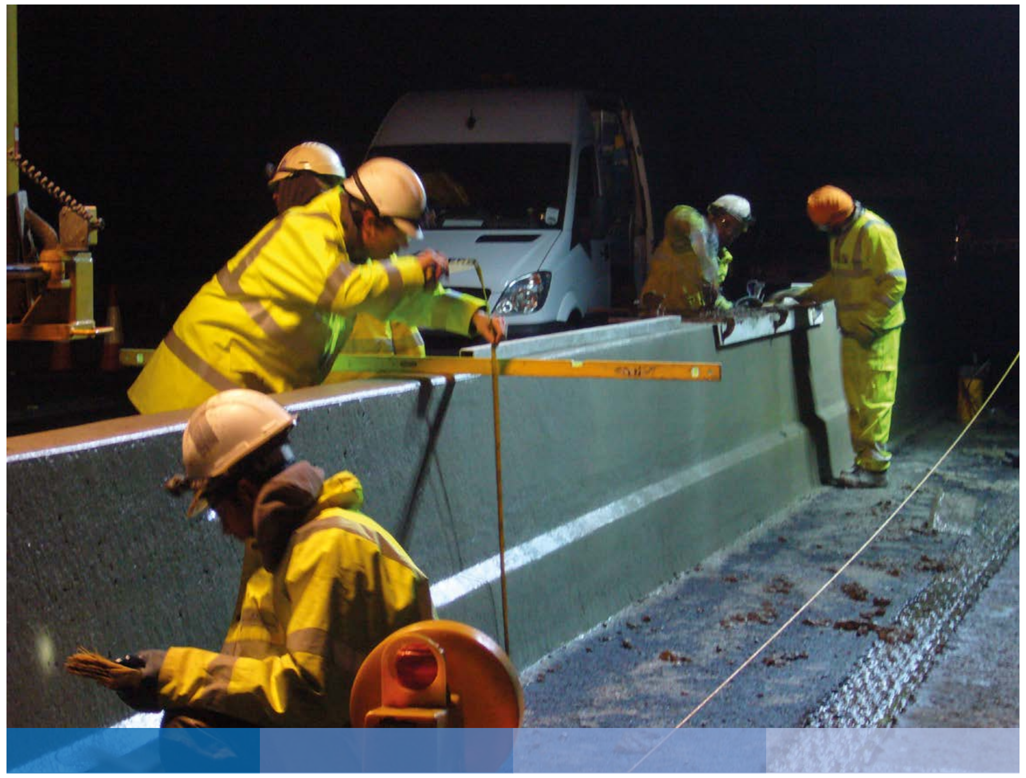
CE marking is a declaration by the manufacturer that the product meets all the requirements of the relevant European legislation. CE marking is designed to remove trade barriers across the EU, giving companies easier access into the European market to sell their products without adaptation or rechecking. From 1st July 2013 onwards CE marking will be mandatory for all permanent safety restraint barrier products throughout the EU.

EN1317 is the product standard for vehicle restraint systems. Part 5 contains annex ZA, the "harmonised" part of the standard which is the basis for CE certification and marking.

Concrete safety barriers must comply with the clauses of annex ZA of EN1317-5 so that the barrier system is installed as tested to the Type Testing (TT) and in accordance with the Manufacturer's Installation Manual. All barriers are subject to the Factory Production Control (FPC) conditions for manufacturing processes.

Precast barrier systems, amongst which all types of steel guardrails, attain their CE mark on the barrier elements. This is because precast systems are manufactured in a factory. The installation of precast barrier is carried out at a separate location to the place of manufacture. Therefore it is essential that the elements are assembled according to the as tested product. By contrast in situ concrete safety barriers are manufactured on site and therefore the installed system could carry the CE mark e.g. the Britpave surface mounted CSB.

Concrete safety barrier constructed under BBS license audit conditions Photo: BBS Barriers



8. PROTECTION OF MOTORCYCLISTS

Example of a motorcyclist protection device, installed to an existing steel guardrail Photo: L. Rens

Vehicle restraint systems are primarily designed to contain and redirect cars, buses and trucks. That means that they do not necessarily provide protection to other road users, in particular motorcyclists. On the contrary, in some cases road equipment can be an obstacle itself and pose impact hazards for two-wheelers. This is particularly true for wire-rope barriers and for conventional steel barriers fixed to steel posts. On the other hand, concrete barriers with smooth continuous surfaces have seldom been reported as dangerous road equipment for powered two-wheelers. [Ref. 7]

In different countries protection devices have been developed in order to protect motorcyclists, having fallen from their vehicle and whilst sliding along the ground, from hitting the sharp cutting edges of the steel profiles. In many European countries, these devices are already being installed in dangerous spots, mainly curves with a small radius.

At the same time, research has been done on methods for testing these devices (in Germany, Portugal and Spain). Based on the Spanish test method, a normative reference test has been discussed, and has become part 8 of the EN 1317 series, but under the form of a European Technical Specification CEN/TS 1317-8 "Motorcycle road restraint systems which reduce the impact severity of motorcyclist collisions with safety barriers". In the future, these Technical Specifications (TS) may be transformed into a real European Standard EN.

In the selected test, only the "sliding" configuration is considered. (The German method also provides assessing the risk for cross-over accidents.) The impact conditions are the impact angle (30°), the speed (60 and 70 km/h) and the choice of impact point (3 different possibilities). In addition, the dummy that is used for the tests hits the protection device (or the barrier) with the head first, which can be considered as the most dangerous but also a rather unlikely situation. The test consists of measuring forces on the head and neck which are related to severity levels HIC 650 or HIC 1000 (HIC = Head Injury Criterion).

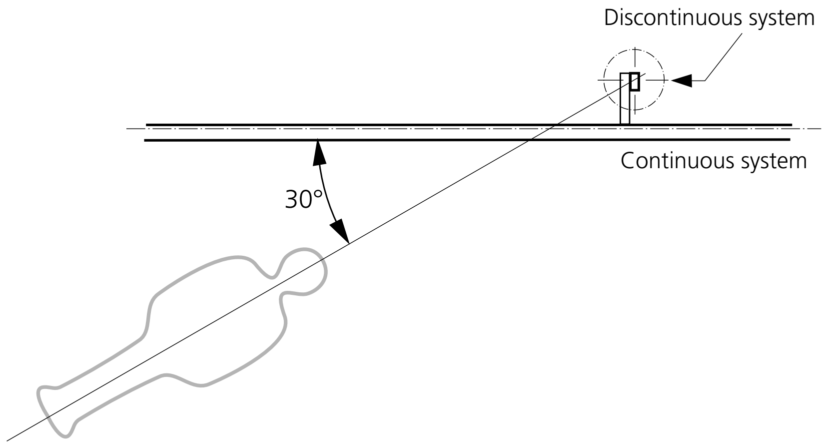


Figure 5: one of the three impact configurations for the testing of motorcyclist protection systems

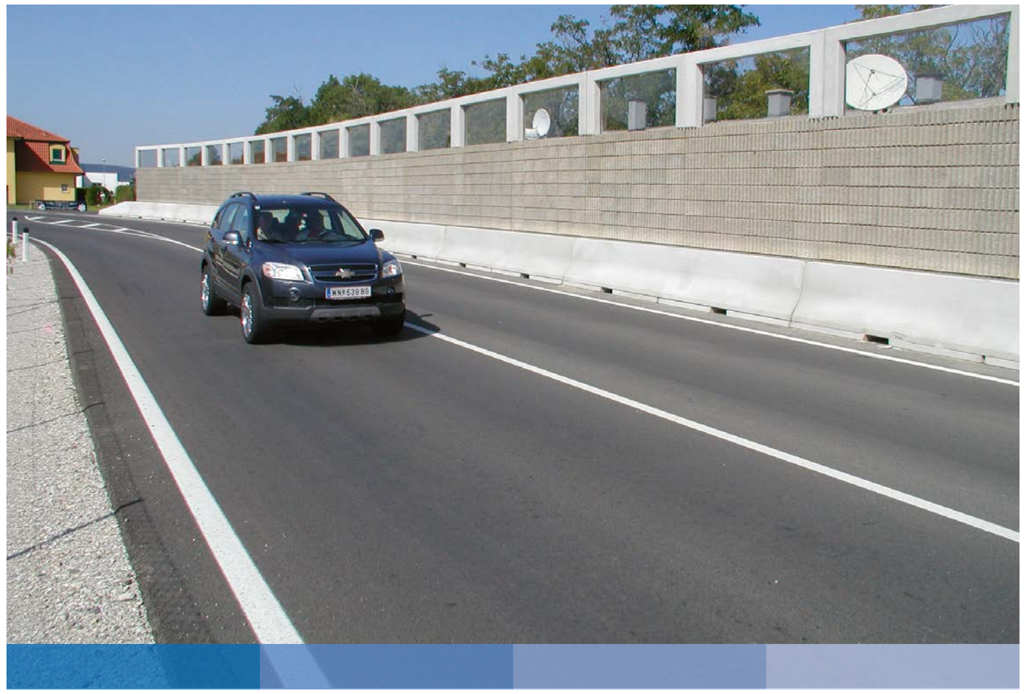
Due to the absence of support posts, concrete safety barriers, whether slipformed or precast, have a limited risk of impact injuries to motorcyclists.

Example of a cast in situ concrete step barrier Photo: L. Rens

9. ROAD RESTRAINT SYSTEMS AND NOISE BARRIERS

Different standards exist for road restraint systems (series EN 1317) and for noise protection devices (series EN 1793 and 1794). Nevertheless, both can be combined in one system and be tested and approved for each of the functions.

Another solution consists of installing approved barriers, e.g. the step barrier, in front of many sorts of standardised noise protection devices.



Example of a combined system of vehicle restraint system and noise barrier

Photo: Deltabloc

Example of a concrete step barrier installed in front of a noise barrier

Photo: L. Rens

10. SUSTAINABILITY OF CONCRETE SAFETY BARRIERS [REF. 10]

SUSTAINABLE DEVELOPMENT

Sustainable development is defined by the World Commission on Environment and Development as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*.

The following principles are identified to assist in its delivery:

- Living within environmental limits
- Ensuring a strong, healthy and just society
- Achieving a sustainable economy
- Promoting good governance
- Using sound science responsibly
- Effectively, sustainable development involves successful integration across the 'triple bottom line' of environmental, economic and social issues.

SUSTAINABILITY OF CONCRETE

Concrete is one of the most versatile and durable construction materials known to man, making it the most widely used construction material in the world. Concrete is also one of the more sustainable building materials when inherent performance properties are taken into account.

Photo: GIVASA

ENVIRONMENT

The cement and concrete sector is committed to an on-going, concerted and coordinated effort to reduce its impact on the environment. Key issues include:

- Reductions in polluting and greenhouse gases during production;
- Efficient use of resources by way of re-used materials and by-products from other industrial processes, such as water, aggregates, fuel or alternative cementitious materials;
- Recycling and reduced reliance on quarried material;
- Environmental rehabilitation after industrial activity has ceased;
- Development of low-energy, durable and maintenance-free buildings and structures.

SUSTAINABLE CONSUMPTION AND PRODUCTION

Production of concrete barrier

Concrete is specified according to EN 206 or EN 13369 (precast). Thanks to the use of blended cement types or the addition of fly ash or ground granulated blast furnace slag, the embodied CO_2 of the barrier can be significantly reduced.

Furthermore, the use of recycled aggregates such as recycled concrete aggregate (RCA) is permitted and technically feasible in concrete barriers.

Construction Cost

Independent studies comparing the construction costs of various barrier systems confirm that the concrete barrier is an exceptionally competitive product.

In addition, with the cost of land being high and space limited, the maximum number of traffic lanes can be obtained by the low working widths provided by concrete barriers. Current steel barrier systems do not offer similar reductions to working width.

In 2007, Britpave commissioned engineering bureau Ove Arup & Partners Ltd. to undertake cost comparison studies [Ref. 1-2-3] of various steel and concrete central reserve systems. Assuming typical road layouts, this work looked at both basic barrier construction costs and the influence of different central reserve layouts and lighting column options. In terms of barrier costs alone, this work confirms that surface mounted concrete step barrier (H2, W2) compares favourably with steel systems, which provide inferior containment (N2) and working width (W3 or W4). For equivalent containment levels (H2), continuous deformable steel systems are considered by Arup to be prohibitively expensive.

Investigating central reserve layouts and lighting provision costs, Arup also reported that a concrete step barrier on a fully hardened central reserve is less expensive than an un-tensioned, corrugated steel beam solution with equivalent containment (H2), sited on a soft central reserve. Similarly, Britpave surface-mounted wide CSB profile with integral cable troughs and mounted lighting columns, constructed on fully hardened central reserve, provides a more economic solution than un-tensioned, corrugated beam barriers constructed on a central reserve with socketed lighting columns.

Maintenance and service life cost

With a service life of at least 50 years, compared with around 20 for steel solutions, concrete barriers offer significant comparative cost savings in terms of end-of-service barrier replacement alone.

Virtually maintenance-free, even after severe impacts, further high potential savings to the tax-payer can be achieved. In addition, the inherently high containment level of concrete safety barriers effectively eliminates crossover incidents, which improves safety and avoids accident recovery costs as well as insurance claims. Congestion, resulting from accidents and routine road maintenance, costs society a lot of money. By increasing levels of motorist safety and reducing maintenance requirements, concrete barriers help to reduce this cost considerably.

Traces of tyres on a concrete safety barrier, showing its resistance to vehicle impacts

Photo: L. Rens

Example of corrosion of a steel guardrail

Photo: W. Kramer

CLIMATE CHANGE AND ENERGY

Embodied CO_2

Comparisons undertaken using industry-agreed values for construction materials indicate that concrete barriers out-perform competing steel solutions in terms of levels of embodied CO_2. Table 2 of Britpave publication BP42 [Ref. 10] which compares material impacts only (including material production, manufacture and delivery to site), clearly shows that the average embodied quantity of CO_2 in a concrete step barrier (105 kg/m for the Britpave surface mounted concrete step barrier) is lower than competing N2 (156 kg/m) and, more applicably, H2 (549 kg/m) steel alternatives over a 50-year period. Indeed, even average values for dual, surface mounted concrete step barrier (247 kg/m) and wide concrete step barrier (205 kg/m) solutions out-perform comparable H2 steel solutions.

Whole-life environmental impact

While calculations of embodied CO_2 and other greenhouse gases are important, whole life performance should always be considered, given that it is the in-service impacts of buildings and civil engineering structures that typically dominate.

With a maintenance-free service life of at least 50 years, concrete barriers require minimal levels of service-life maintenance activity and related traffic management. As a result, low levels of road-user disruption and congestion are predicted. As the effectiveness of catalytic converters for vehicles idling or travelling at low speed is dramatically reduced, the net result is an overall positive impact on service-life greenhouse gas emissions.

Steel barriers have a design life of around 20 years and require maintenance after vehicle impact, an activity often requiring traffic management and lane closures which contribute to congestion. As such, over the 50-year lifecycle of concrete barriers, the comparable amount of work, vehicles and energy required to install and maintain a steel barrier is likely to be much higher.

NATURAL RESOURCES

Recycling

Concrete barriers can be constructed using a wide range of secondary and recycled materials and, at the end of their design life, are fully recyclable.

Concrete barriers are 100% recyclable – a practice now commonplace – providing good quality secondary aggregates, which are useable in a wide range of applications.

While steel barrier systems are recyclable, the fact that they are typically hot-dip galvanised to prolong their service life introduces economic and environmental constraints. As galvanised steel is recycled with other steel scrap, the zinc used for galvanising volatilises early in the process and must be collected for reprocessing. Zinc is a chemical waste subject to pollution control legislation and requires appropriate collection, treatment and disposal (or recycling) processes.

In-service pollution

Research since 1997 confirms that highway run-off from rural trunk roads and motorways contains pollutants such as metals, hydrocarbons, salts and nutrients as well as microbial waste. Sources of pollution are reported to include construction, operation and road maintenance operations. Steel safety fences and street furniture are known to be a significant source of heavy metals in run-off, particularly in winter months.

Concrete does not contain or leach contaminants and presents no risk to environmental pollution when used in highway applications. This is confirmed to be true even when crushed recycled concrete is used in unbound secondary applications.

Highway maintenance programmes – which are more common for steel systems due to their deformability on impact and relatively short design life – are also known to significantly affect sediment accumulation in drainage systems. This impact is clearly minimised by concrete barriers as they require minimal maintenance throughout their 50-year design life and are typically situated on hardened medians.

Rebar impact

While concrete barrier construction typically employs steel strand to limit fragmentation under heavy impacts, the concrete barrier can incorporate rebar, which, depending on the manufacturer, is often manufactured from 100% recycled scrap using an electric arc furnace process. While steel manufacture is generally energy-intensive, it should be recognised that the energy needed to produce one tonne of reinforcing steel is as low as half of that required to produce the same mass of structural-grade steel.

Land uptake

Concrete barriers require less land than all competing barrier solutions. Concrete step barriers with containment levels N2 and H2 have a working widths of W1 (0.6 metres) and W2 (0.8 metres) respectively, which is lower than for all other competing solutions with similar containment levels.

Ecology

Animals travel within and between feeding areas, territories and even countries. Such journeys are essential for the everyday survival of individual animals as well as for the maintenance of viable populations**.** In addition to the impact of mortality, there is the impact of reduced or prevented wildlife dispersal and the associated severance of wildlife territories and habitats.

Whilst there are no known data available to compare the impacts of roads with or without concrete barriers on wildlife, one can easily imagine that that the installation of a solid central barrier could serve to increase wildlife mortality and habitat fragmentation. It is acknowledged that, by the very nature of its design, a steel barrier is less likely to block animal dispersal, compared with the solid face of a concrete barrier. However, in order to minimise wildlife casualties, animal population fragmentation and risk to road users from vehicle collisions with wildlife, it is not the type of safety barrier used that is important. Rather, it is the provision of effective and targeted mitigation measures that holds the key to reducing the environmental impact of road safety barriers.

The innovative design of 'eco-passages', such as culverts, bridges, viaducts and overpasses across roads, in conjunction with effective and well maintained wildlife fencing for larger species, is considered to present the greatest opportunities for reducing the impacts of roads and road safety barriers on wildlife.

Rather, it is the provision of effective and targeted mitigation measures that holds the key to reducing the environmental impact of road safety barriers. Such mitigation measures have included a modification to a permitted weephole design to allow safe passage of wildlife through the concrete barrier.

CREATING SUSTAINABLE COMMUNITIES

Construction worker health and safety

Highway authorities and contractors are committed to road worker health and safety by reducing exposure to live traffic and lessening risks when on the network, as well as improving driver awareness and education. These include an urgent review of operations that require road workers to be exposed to live traffic, with a view to reducing risks, and a revision of maintenance priorities to reduce the number of visits and ad-hoc repairs and maintenance to cut the need for road workers to be on the network.

Concrete safety barriers mostly require no maintenance after impact by a vehicle, with the resultant avoidance of the repair and associated traffic management activities.

Motorist safety

Concrete barriers provide excellent levels of motorist safety. Ove Arup & Partners Ltd., one of the world's leading consultants, has undertaken EN 1317-compliant crash tests and related computer simulations to investigate the potential for injury from collisions with concrete step barriers and alternative safety barriers. EN 1317 uses ASI values for assessing the impact on vehicle occupants and the ASI values recorded for concrete barriers tend to be higher than those for deformable steel barriers. However, the study proves that there is no direct correlation between the measured ASI values and the level of injury. Details of the study are explained in the part "HIC versus ASI" on pages 11-12.

In reality, concrete barriers also help to eliminate injury and deaths associated with cross-over accidents, barrier intrusions and deflections, and loss of vehicular control on soft verges, all of which are typical of steel barrier systems. Requiring almost no maintenance or repair after a collision, concrete barriers will also help to avoid motorway accidents in coned areas, such as those required for maintenance activities.

Visual impact

Visually, concrete barriers provide a smooth, continuous structure that is relatively consistent in terms of texture and colour. Although colour is likely to change with time, due to the natural degradation of water-based curing compounds and weathering, it should remain consistent. From the motorist's visual perspective, concrete barriers present a low-level screen that helps to reduce glare at night from oncoming traffic.

From a motorist-safety point of view, the visual impact of concrete barriers has been reported to potentially reduce average traffic speeds.

Noise impact

In 2005, Britpave commissioned a study to investigate the impact on roadside noise arising from the presence of concrete barriers in the central reserve. Arup Acoustics conducted a field study and theoretical analysis to establish any differences in roadside noise levels, comparing concrete and steel central reserve barriers.

The results from the empirical and theoretical studies show that there is a negligible difference in roadside noise levels comparing concrete and steel central reserve barriers.

11. DESIGN AND CONSTRUCTION

GENERAL

Concrete barriers can be applied in different situations. If a central reserve has no obstacles, a double-sided profile is the obvious choice. When there are obstacles in the central reserve, such as lighting poles or columns of portals, a double single-sided profile can be chosen as an appropriate solution. It is also technically feasible to build widened concrete barrier profiles, in which lighting poles can be integrated.

Drainage

When the slope of the pavement runs towards the barrier, removal of rainwater should be taken into account. Drainage near the barrier can be achieved with transverse openings at the foot of the barrier, whether or not combined with a drainage system.

PRECAST CONCRETE SAFETY BARRIER

Precast concrete barrier elements are factory produced in reinforced concrete. At the end of the elements, producer-patented connection systems are constructed, allowing the elements to form a rigid chain. For systems placed on main roads, this interconnection is required. The standard length is usually 6 m; the mass associated with this length can be handled with an assembly crane. With elements of 6 m, curves with a radius greater than R = 250 m can be achieved. For smaller radii, shorter elements should be applied. The elements are already provided with openings at the bottom for drainage / throughput. The openings are also used for handling and placement of the elements.

Note: Suppliers of precast concrete barrier elements usually have several types / profiles of barrier systems, suitable for different performance classes and temporary situations.

Assembly

The installation of precast concrete barriers is usually executed by the supplier. The principal contractor must ensure the right place for installation and a flat surface, usually asphalt. The barriers are installed directly from the truck. Additionally, for large quantities, a depot in the vicinity of the site is made, from where the barriers are transported to the site.

Installation of precast concrete barriers

Photo: L. Rens

In situ concrete safety barriers

The in-situ cast barrier is built on a base surface of asphalt or lean concrete. Construction is done with a custom slipform paver with a mould. Production rates of 400 to 600 meters are achievable. Behind the machine, the extruded profile of fresh concrete should not deform. For this purpose it is advisable to apply a low-slump concrete with crushed aggregates, to obtain a stable mixture.

The following specifications are recommended for the concrete mix in an exterior environment where de-icing salts are used (based on the standard for concrete, EN 206):

- Compressive strength class: C28/35 or C30/37
- exposure class: XF4 or XD3 (use of an air entrainer)
- maximum aggregate size: 22 mm
- slump class: S1 (a maximum slump of 30 mm is preferred)
- minimum 340 kg of cement/m³
- maximum water-cement ratio of 0.50
- crushed gravel or limestone aggregates
- use of a mix of coarse and fine sand in order to obtain a smooth closed surface

Photo: Wirtgen

Photo: Power Curbers

Photo: Gomaco

Photo: Gomaco

In situ construction of concrete safety barriers with the use of a slipform paver

Photo: Deltabloc International

Photo: Power Curbers

To ensure cracking is controlled, the barrier is typically sawed every 3 to 4 metres to a depth of 5 cm. This sawing happens 6-24 hours after the construction of the barrier. Automated saw cutting systems have been introduced to the industry, which allow for greater accuracy of cutting alignment and depth, whilst also improving worker safety through remote controlled operation.

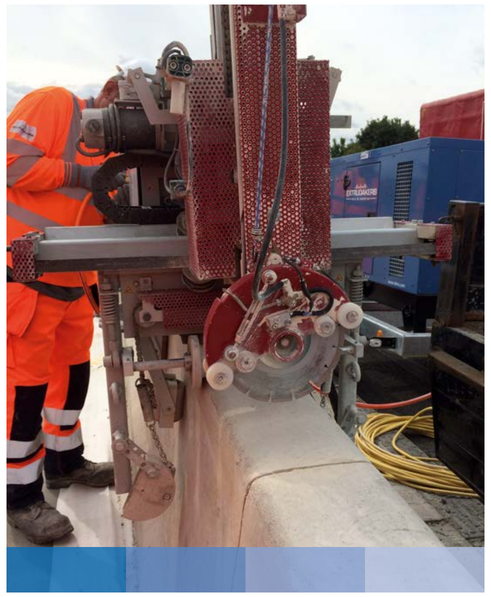


Photo: BBS

12. CONCLUSIONS

Concrete safety barriers, both cast in situ and precast, have been used as vehicle restraint systems for more than 40 years. Their design and construction have been modified and improved in order to comply with the European standards EN 1317. Today, they offer a solution that meets the requirements of durability, safety, economy and environment.

Concrete is known for its durability and robustness. This is also the case for concrete safety barriers which have a service life of over 50 years, do not deform and mostly even stay intact after severe vehicle collisions, and are resistant to all types of climatic conditions.

In terms of safety, a concrete safety barrier offers a high containment and thus reduces the risk of crossover accidents. It is designed to redirect errant vehicles without unacceptable risks for both vehicle occupants and other road users and third parties. Thanks to its smooth continuous surface and the absence of posts, the risk of impact injuries of motorcyclists is also reduced.

The economic benefits are the relatively low initial construction cost, the rapid and easy installation and the fact that concrete barriers hardly need maintenance over their service life.

The environmental strong points are inherent to the use of concrete, which in itself is a sustainable material with limited embodied energy and carbon footprint considered over the entire lifecycle and with the possibility of using recycled aggregates. Thanks to the minimum working width, concrete barriers require less space and only one concrete barrier is needed in the central reservation to serve both sides of the road. In addition, they cause no pollution and are fully recyclable at the end of life. As it is a maintenance-free system, road availability is increased and traffic congestion reduced.

Finally, concrete safety barriers, precast and cast in situ, exist in a wide range of complete and tested solutions. All precast systems and in situ cast concrete safety barriers, built according to a proprietary design, carry the CE-mark. In the case of in situ cast barriers, this includes even the manufacturing, thus the installation of the barrier.

Concrete safety barriers are a safe and sustainable choice!

Photo: Omnibeton – Deltabloc

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Photo: Agentschap Wegen en Verkeer, Flanders, Belgium

Photo: E. Schelstraete – E42 Froyennes

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