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Road restraint systems — Determination of collision forces on bridges as a result of an impact of a vehicle on a restraint system
Fahrzeugrückhaltesysteme - Ermittlung der von Fahrzeugrückhaltesystemen auf Brücken übertragenen Aufprallkräften

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Road restraint systems - Determination of collision forces on bridges as a result of an impact of a vehicle on a restraint system Fahrzeugrückhaltesysteme - Ermittlung der von Fahrzeugrückhaltesystemen auf Brücken übertragenen Aufprallkräften

Fahrzeugrückhaltesysteme - Ermittlung der von Fahrzeugrückhaltesystemen auf Brücken übertragenen Aufprallkräften

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

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European foreword

This document (CEN/TR 18242:2025) has been prepared by Technical Committee CEN/TC 226 “Road equipment”, the secretariat of which is held by AFNOR.

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Introduction

According to EN 1991-2, collision forces on vehicle restraint systems (VRS) have to be taken into account in bridge design so no damage is sustained by the bridge structure.

Over time traffic density and the weight of vehicles has increased throughout Europe, as a consequence Road Authorities have started to require VRS with higher containment levels to protect the edge of bridges. Due to these higher containment levels, the risk of bridge deck damage increases. It is important for designers to account for realistic load levels.

Bridge designers apply the loads from EN 1991-2 in order to define the collision loads from a VRS, but currently there is no guideline how to determine collision loads for VRS; just four load levels are proposed.

Therefore, some countries already have established different national procedures and methods to classify VRS; either by calculation, calculation aided by testing or just by testing.

The design of the anchoring system is part of the design of the VRS as stated in EN 1317-2:2010 (paragraph 4.2).

The purpose of this document is to catalogue common best practice methods and procedures to classify VRS according to the EN 1991-2 collision force levels.

1 Scope

This document gives guidance on principles and methods to determine the forces due to the collision of an errant vehicle with a vehicle restraint system (VRS) in bridge design and classify VRS with load.

2 Normative references

There are no normative references in this document.

3 Terms and definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at https://www.electropedia.org/

— ISO Online browsing platform: available at https://www.iso.org/obp

3.1
collision force on bridges
forces transferred to the bridge structure and the bridge cap due to the impact of an errant vehicle on a VRS

3.2 Abbreviations

VRS	vehicle restraint system
M	moment
H	applied horizontal load
M/H curve	maximum' moment of resistance' – 'maximum horizontal force' curve of the anchored steel safety barrier

4 Determination of load levels

4.1 General

When choosing a VRS, it is important that the bridge designer has accurate information pertaining to the maximum load levels which that particular VRS will impact on the bridge deck. Methods to determine this load level are given in specifications. The different methods given in this standard may not lead to the same results. EN 1991-2 gives the load to be considered for accidental design situations.

The different methodologies in determining the characteristic capacity of a VRS are described in 4.2.

A typical bridge VRS may be a discontinuous face barrier, made completely or partly in metal, with longitudinal elements supported by discrete posts anchored to the deck (*discontinuous face barrier*), or continuous face barriers, generally made from concrete or from metal, with or without discrete anchorage to the deck (*continuous face barrier*).

4.2 Methodologies to determine collision forces on bridges

4.2.1 Determination of collision forces by analytical methods

4.2.1.1 General

In principle analytical methods can be used for structural design according to EN 1991-2:2003, 4.7.3.3 (1) or for determination of local characteristic resistance of VRS (e.g. design of bridge cap and the connection between cap and structure) according to EN 1991-2:2003, 4.7.3.3 (2). The methods can be used for anchored barriers or for freestanding VRS (or a VRS with a non-structural weak anchoring for location fixation only).

For structural design: 4.2.1.2 - 4.2.1.5

For determination of local characteristic resistance of VRS: 4.2.1.6 - 4.2.1.7

The M/H 'maximum' moment of resistance' – 'maximum horizontal force' curve of the anchored steel safety barrier is determined by an analytical method.

This curve corresponds to the weakest element of the configuration, which may be the post or the anchoring in concrete.

To protect the bridge structure the results of the calculation may have additional safety factors.

4.2.1.2 *M/H* curve for the post

4.2.1.2.1 *M/H* curve of the post

The *M/H* curve of the post is calculated:

— according to the strong axis;

— without taking account of any instability phenomena of the post or its components.

The maximum resistance of the post is determined in accordance with the principles of the EN 1993-1-1 using the upper limit of the tensile strength of the grade of steel used, as determined in the EN 10025-2.

The curve area to be taken into account is defined by:

— *M/H* = 0,25 m: physically, no impact is possible at a height below 25 cm.

— *M/H* = real height of the post: physically, no impact is possible above the real height of the post.

4.2.1.2.2 Post with plinth at the base

In case of plinth at the base, the process is as follows:

a) The *M/H* curve of the post is first calculated as if there were no plinth. Each point of the curve is then increased as follows:

1) $H_n = H$

where

H is the applied horizontal load

H_n is the applied horizontal load for each application height ($_n$)

2) $M_n = M + H*h_{plinth}$

where

M	is the moment
M_n	is the moment for each horizontal load applied
H	is the applied horizontal load
h_{plinth}	is the height of the plinth

b) The *M/H* curve of the reinforced area just above the base plate is calculated.

4.2.1.2.3 Post with a variable cross section

In the case of a post with variable cross section, the process is as follows:

a) Determine at least 4 sections for which the *M/H* curves are calculated.

These are:

1) the section at the base of the profile (at the connection with the base plate);

2) the smallest section of the profile (probably above the profile);

3) the section(s) at the location of a discontinuity;

4) other section(s) at one or more pertinent locations) (= as far as possible distributed at the top of the post.

b) The *M/H* is calculated for each section chosen as defined in 4.2.1.2.1, *M/H curve of the post*

Next, each point of each curve is raised:

1) $H_n = H$

where

H	is the applied horizontal load
H_n	is the applied horizontal load for each application height ($_n$)

2) $M_n = M + H*h_{section}$

where

M is the moment

M_n is the moment for each horizontal load applied

H is the applied horizontal load

$h_{section}$ is the height of the applied horizontal load for each section

4.2.1.3 *M/H* curve for the anchorage of barriers

The maximum resistance curve for anchorages calculated as follows:

$$\left(\frac{H}{H_u}\right)^2 + \left(\frac{M}{M_u}\right)^2 = 1$$

To determine M_u and H_u the characteristic value of $f_{u\ max}$ needs to be declared by the manufacturer.

where

$f_{u\ max}$ is the upper limit for the tensile strength of the anchorage (in kN/m^2) as determined in EN 10025-2

H is the applied horizontal load

H_u is the upper limit for the applied horizontal load

M is the moment

M_u is the upper limit for the moment

4.2.1.4 *M/H* curve of the post and anchorage

The *M/H* curves for the post and the anchorage are compared and combined according to one of the situations below. Only the pertinent area (0,25 m < *M/H* < real height of post) is considered.

— Situation 1: one curve is completely below the other(s). This curve determines the weak element and therefore the maximum forces transmitted;

— Situation 2: the curves cross. In this case we can consider the weakest combination of parts of the curves;

— Situation 3: there is only one curve available. This is considered as decisive.

4.2.1.5 *M/H* curve of the base plate

In the particular case where the resistance of the safety barrier is achieved by bending the base plate and not the post, this can be taken into account in the determination of the *M/H* curve of the post and anchoring posts assembly. As such systems are at present unknown, the principles (which are similar to the determination of the *M/H* curves above) are not described in detail.

4.2.1.6 Determination of local characteristic resistance of discontinuous face barriers

The approach in 4.2.1.2 applies with the following deviations.

Use of yield strength rather than the upper limit of tensile strength in accordance with EN 1993-1-1.

For a realistic and sufficiently safe assessment the supporting effect of longitudinal elements (horizontal tension band) are considered in the static system, taking into account the VRS behaviour observed during type testing.

4.2.1.7 Determination of local characteristic resistance of continuous face barriers

The following approach applies for heavy concrete barriers. Light weight barriers (e.g. steel) or other systems which are at present unknown, are not covered. The use of engineering methods representing resistance behaviour of VRS (e.g. anchorages) is appropriate for the assessment of other VRS not covered.

Both, for free-standing or anchored concrete barriers the resistance is determined by friction forces during assumed movement of the VRS.

Vertical forces resulting from VRS dead load increase due to the vehicle climbing on the traffic face of the VRS. Consideration of the following scenario is appropriate (see Figure 1):

a) Climbing of a tandem axle with the two outer wheels onto the VRS front, axle distance 1,20 m and wheel contact patch 40 cm x 40 cm. For the position of vertical loads it is appropriate to use a height of 20 cm above the surface (e.g. bridge deck or cap).

b) It is appropriate to include in the distribution length of the axle load, the axle distance, the wheel contact patch and a load distribution by 45° within the VRS.

c) EN 1991-2 contains information that is appropriate for determining the vertical axle load:

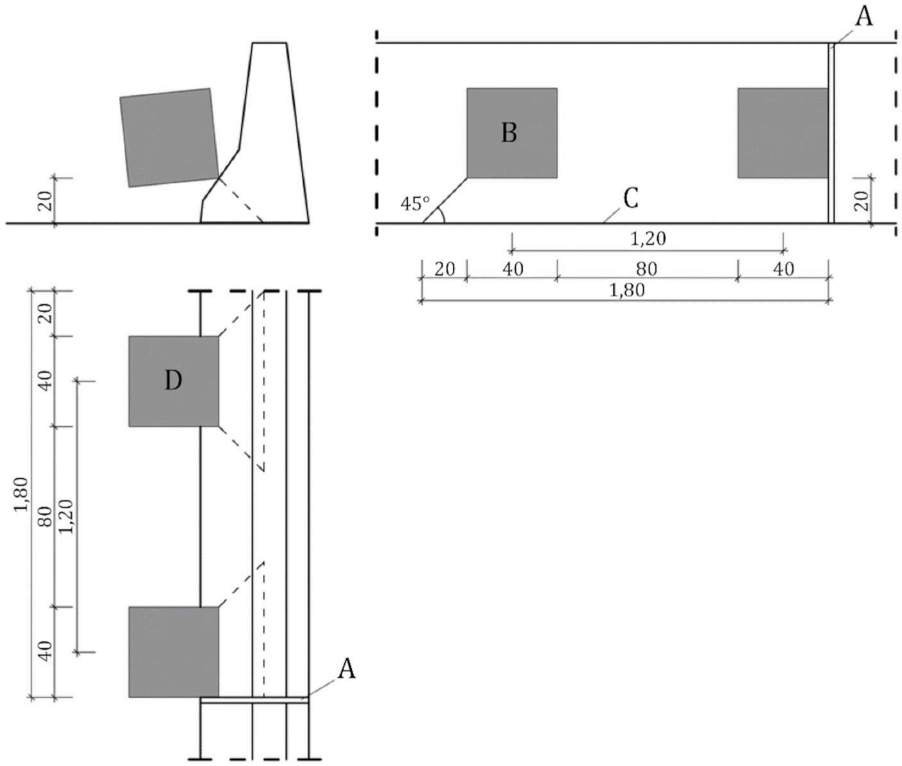
$$0{,}75 \times \alpha Q1 \times Q1K;$$

$$\textit{in case of } \ \alpha Q1 = 1{,}0 : 0{,}75 \times 1{,}0 \times 300 = 225\ kN$$

Where

α	is the load class coefficient
$Q1$	is the applied load
K	is the total support stiffness in the longitudinal direction

The coefficient of friction concrete/concrete varies depending on the surface condition between 0,5 and 1,2. In order to cover all imponderables securely, μ = 1,2 is recommended.



Key

A Joint

B Load per wheel

C Friction surface

D Load per wheel surface 40x40 cm

Friction force = $\mu*(g_{vrs}+(0,75*\alpha_{Q1}*Q_{1k})/1,80)$

Where

μ is the coefficient of friction concrete/concrete

g_{vrs} is the dead load of v_{rs} in kN/m

Figure 1 — Friction of heavy concrete barriers on concrete surface

4.2.2 Determination of collision forces aided by testing

4.2.2.1 General

The identification of maximum loads acting on bridge decks during vehicle collisions with VRS is beneficial for ensuring a safe design of the bridge structure. The most significant collision loads are the overturning moment, the horizontal force and the vertical force; such loads have a distribution on the length of the deck that varies rapidly during the impact. Bridge designers need the highest possible loads to verify the structures, i.e. the values of the highest peaks of each load, averaged over predetermined length and low-pass filtered in time with appropriate cut-off frequency.

In general, the safe design of a VRS includes load limiters that yield at the maximum impact performance yet allowing a safe containment of the vehicle. Nevertheless, usually the maximum possible anchorage -load does not necessarily occur during the containment test. Therefore tests are carried out on test samples representative of the performance of the road restraint systems in terms of load transmission to the ground. The tests are performed until the ultimate failure of the systems, and therefore the effect of any possible vehicle is covered. Values of forces and moments in the different directions are obtained, related to a defined point of the road restraint systems.

The ultimate strength is the maximum resistant capacity, expressed by means of forces and moments, developed by the test sample. It is reached when the structural collapse of the sample occurs, or the fixings or fusible elements break.

A characterization of the road restraint system is obtained in terms of the loads it transmits to the structure, which do not depend on the containment level according to EN 1317-2:2010. This test procedure does not substitute any of the full-scale vehicle impact tests specified by the EN 1317-2:2010standard to determine the conformity of a road restraint system. This procedure defines additional and complementary tests to the vehicle impact tests, which allow to obtain a measurement of the maximum loads in order to apply them to the design or verification of the bridge deck or structure on which the system is going to be installed.

4.2.2.2 Measurement of forces from barrier anchorages

4.2.2.2.1 General

The maximum loads transferred to the bridge deck by the anchorage can be measured by a push-pull test on a barrier component connected to a single anchorage. The provision, by the manufacturer, of the drawings and technical description of the road restraint system sample to be tested, including fixings and specifications for its proper installation, gives the necessary information for the correct determination of the test configuration by the test laboratory. A minimum requirement for the information to provide is given in EN 1317-5:2007+A2:2012[1], subclauses 5.2 and 5.4 .

It is appropriate to include in the definition of the test sample a fixing unit device (i.e. the functional unit used to fix the system to the ground according to the design) and a post fixed to the deck.

This sample allows to characterize the behaviour of the road restraint system, including its fixing device. The deck or structure on which the system is intended to be installed on the road is not evaluated. This deck or structure is replaced by a support tool, which is part of the test installation. Considerations for the provision of a test site allowing suitable installation of the test sample are given below:

a) A main base with enough mass and rigidity characteristics to develop reaction forces to the loads transmitted during the impact test without displacements or deformations.

b) The capacity to measure forces and moments with appropriate sensors in the three coordinate axes. Its structural and measurement capacity being sufficient to resist and obtain all the loads (Forces and moments in the X, Y, Z axes) that are generated in the impact on the test sample.

c) Support substructure-tooling: it is the part of the test installation that is in contact with the test sample and in which the fixing device is inserted or attached. It replaces the target deck or structure on which the system would be installed on the road.

An adequate assembly formed by the base, the sensor and the supporting substructure is appropriate in order to guarantee that its structural resistance is greater than the ultimate resistant force of the test sample, and that its deformation during the test is negligible compared to that of the test sample.

A test can be considered to be valid if, during the test, any damage to the support substructure does not prevent the ultimate strength of the test sample from being reached. In the case of an invalid test, an appropriate course of action would be to carry out the test again using a support substructure with enough resistance.

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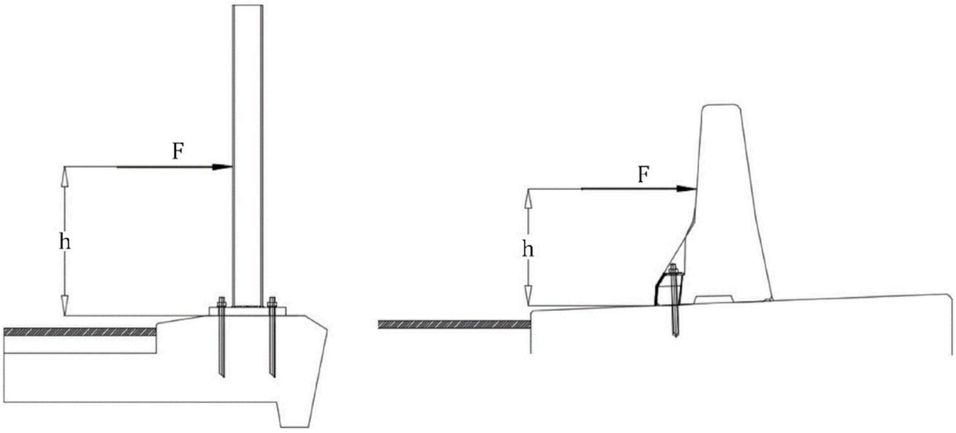
[1] Document impacted by AC:2012

It is appropriate to install the test sample fixed on the test installation using the same fixing device foreseen in the design of the system, without any modification of its material or geometry that affects its behaviour in terms of load transmission.

In case of screwed elements, it is appropriate to take into account all the components (including washers) provided for the joint, along with the applied torque.

The basically horizontal push or pull force F, oriented from the traffic side toward the barrier, is applied perpendicularly to a single barrier post for discontinuous face barriers (see Figure 2 a), and to a single element with a single anchorage for continuous face barriers (see Figure 2 b).



a) Discontinuous face barrier b) Continuous face barrier

Key

h Height of load

F Applied force

Figure 2 — Push tests on parapets anchorages

It is appropriate to apply the force at the maximum possible height, looking for the maximum overturning moment, and at the lowest possible height, for the maximum shear force. If not defined by national regulations, it is appropriate to consider that the top height is the mid-height of the top longitudinal element, and that the lowest height is 0,5 m above the post base.

NOTE In Spain, two impact heights are defined, called A and B:

— Height A: is equal to the maximum height of the test sample, minus 0,2 m. This height is applicable to all systems.

— Height B: is equal to the minimum of the following two measurements:

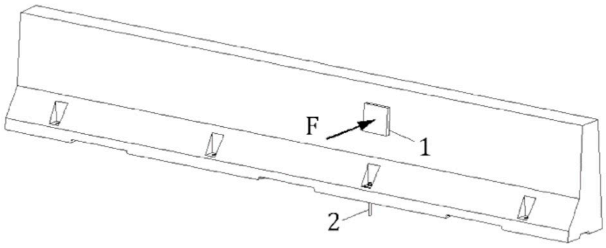
  — 0,45 m

  — for road restraint systems with longitudinal elements intended to come into contact with vehicles to carry out their containment, the average height of the lowest of them, with a minimum value of 0,25 m.

Height B only applies to systems where the difference between height A and height B is greater than 0,30 m.

For discontinuous face barriers, additionally the measurement of longitudinal forces is required. In this case two more tests are needed, with the push-pull force in the longitudinal direction, at the same heights of the perpendicular tests.

Distributing the force over an adequate area avoids the occurrence of local damage to the barrier (Figure 3).



Key

1 Load distributing pad

2 Anchorage

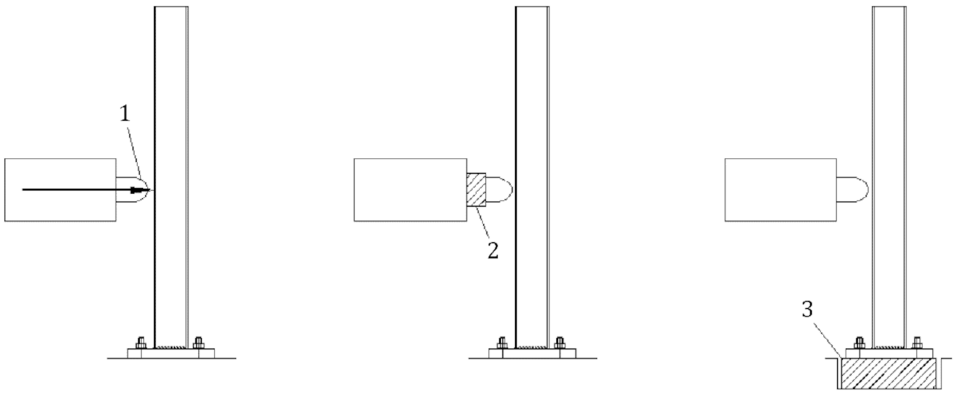
F Applied force

Figure 3 — Force distributed over an adequate area

When bent, posts with asymmetrical cross section (e.g. U section) or with narrow cross section (e.g. IPE section) tend to twist significantly. In real life such twisting does not occur as long as the post is connected to the barrier. Thus, it is appropriate to prevent it from occurring in the push-pull tests by the use of adequate fixing devices.

During the test, it is appropriate to measure continually and to record the force using an appropriate sampling rate.

The force can be measured by a load cell installed in different locations, as shown in the examples of Figure 4, *Force measurement*. In any case, placing the load cell under the post base will result in the most comparable measurements.



Key

1 Hammer

2 Load cell in the hammer

3 Load cell under the post base

Figure 4 — Force measurement

Recording the displacement of a point on the hammer (or of an appropriate point on the system), with a sampling synchronised with that of the force, allows the plotting of a force-displacement diagram, should this be required.

Adequate test data can be obtained by testing beyond the failure of the anchorage system.

Any failure, deformation or cracking of the test sample foundation during the test will invalidate the tests results since the test is looking for the failure loads of anchorage system. A properly sized steel foundation can be also be used.

4.2.2.2.2 Dynamic measurements

In a dynamic test, it is appropriate to ensure that the strain rate in the material that yields in the anchorage area is close to the one in the relevant type test.

This can be done quite simply by hitting horizontally the component of the VRS with an appropriate mass, at a speed close to the lateral component of the impact velocity of the vehicle in the initial type testing test with a mass sufficient to produce a deflection beyond the failure of the anchorage. The mass can be brought to the proper speed by gravity, as with a pendulum, or by other means, as with a sledgehammer or with a rigid bogie.

It is appropriate to carry out the tests by launching an impactor device, with enough impact energy to cause the ultimate failure of the test sample, using an impactor with a total mass of at least 1500 kg, a width of 600 mm and height of 300 mm. The laboratory may extend the width of the impactor if considered necessary to bring the sample to collapse.

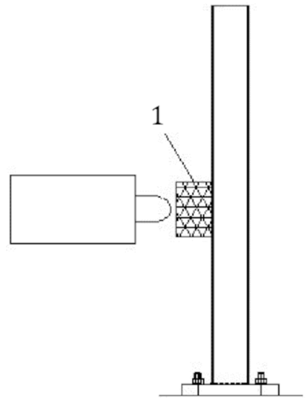
During the tests, loading the test sample so as to reach its ultimate strength ensures that the loads obtained are the maximum that can occur. It is desirable to verify the failure of the fixing device, the controlled detachment of the test sample, or deformations or breakage of materials that denote the structural exhaustion of the tested assembly.

The desirable impact speed is (35 ± 2) km/h. measured by an appropriate method, not more than 0.5m from the impact point on the approach path.

In dynamic tests much attention must be paid to the installation of force transducers. The inertial effects and limited resonant frequency (lowered when attaching additional masses) could cause measurements problems with load cells, especially in highly dynamic impacts.

For a discontinuous face barrier anchorage, the hard impact of the hammer on the post produces vibrations of the post, mostly in bending, whose frequency is too low to be filtered and whose amplitude is so great that the measurement and the loading of the yield area can be completely altered. This hard impact on a post does not occur in a real collision against a VRS, because of the deformation of rails, of spacers and of the vehicle outer body.

It is desirable to reduce the amplitude of the vibrations generated by the impact of the hammer to an acceptable level by introducing a cushion to mitigate the impact (Figure 5).



Key

1 cushion

Figure 5 — Cushion to mitigate the hard impact

Cushion type, size, thickness and stiffness/density can be chosen by the test laboratory according to post strength (huge strength variation among different parapets)

A suitable cushion can be made of aluminium honeycomb with appropriate dimensions. For a certain post, impact height *h* and impact speed, a cushion is adequate if it deforms at least 50 mm without bottoming.

For a continuous face barrier the dynamic test cannot be done because the mass of the element is too large. The impact of the hammer would be reacted completely by the inertia of the element with virtually no load on the anchorage, and the element would suffer unacceptable damage.

During dynamic tests, it is appropriate to record the force and the displacement with a sampling rate of at least 10 kHz, with the sampled data being reported using a low-pass filtered with a CFC 600, as described in the ISO 6487, and an adequate Channel Amplitude Class (CAC) to avoid both saturation and excessive staggering during the acquisition process.

It is desirable to acquire at least an additional 500 ms at the beginning and the end of the contact between the impactor and the sample, in order to minimize possible unwanted effects in the filtering stage.

Accurate dynamic measurements are not easy, but performing the dynamic tests can be easier, because they do not require a strong reaction point as the static tests.

In order to ensure conformity between the elements tested and the technical documentation that accompanies them, it is desirable to carry out verification tests on the geometry, materials, mechanical characteristics and coatings (if applicable), in specialized laboratories. It is appropriate that the samples for these tests be taken from the same batch sent by the manufacturer to the laboratory to carry out the load measurement tests.

Additional information necessary to fully describe the behaviour of the test sample and its fixing device can be obtained by filming with high-speed cameras operating at a minimum of 1000 frames per second. As a minimum, the following arrangement is desirable:

- A high-speed camera, placed laterally to the system, which covering the entire test sample.
- A high-speed camera, placed obliquely in order to obtain a front-side view of the lower part of the sample.

The test conditions may be modified exceptionally if the test laboratory considers that, due to the characteristics of the sample, its behaviour under the nominal test conditions is qualitatively different from that which will cause the transmission of maximum forces and moments – any modifications in the test conditions being described and justified in the test report.

The following is the minimum data appropriate for the preparation of the test report:

a) Pre-test data.

  1) The mass of the impactor.

  2) Pictures of the test sample.

  3) Documentation related to the sample and its installation.

  4) Position of the reference point for the expression of loads.

  5) Impact trajectory.

  6) Impact height.

b) Test data.

  1) Impact speed.

  2) Forces and moments transmitted by the test sample.

  3) Videos of the behaviour of the test sample using high-speed cameras.

c) Post-test data.

  1) Description of damage to the test sample.

  2) Description of damage to the fixing device.

  3) Pictures of the test sample, the fixing device and the support substructure.

4.2.2.2.3 Static measurements

In static or quasi-static tests the velocity of the point of application of the force is lower than 1,0 cm/s. There is no impact and the evolution of the test can be easily observed directly.

On the other side the static application of a horizontal force requires a strong reaction point, which generally is not required in dynamic tests. This may be impossible or extremely difficult to achieve in the case of very high containment parapets.

Due to the complexity of the design of some posts (with asymmetric and variable cross sections) it is often not feasible to try to avoid their tendency to twist during impact, when talking about dynamic impact tests and 4 different configurations (2 directions and 2 heights). There is not such a big problem when talking about quasi-static tests.

The relative weakness of quasi-static tests is the fact that they do not capture the rheological effects, i.e. the possible increase in yield stresses caused by strain rate.

In some cases, as for example, in the case of a metal post at the strain rate typical of initial type testing tests, the yield stress of mild steel has typically an increase between 15 % and18%, while the one of a high grade steel only between 7% and 10%.

4.2.2.3 Complementary evaluation of the collision loads by Computational Mechanics

4.2.2.3.1 General

The push-pull tests allow the measurement of the overturning moment and, if the height h is correct, of the horizontal lateral force on a single anchorage. These loads can be used to design the bridge deck structure.

The loads originated by the collision on the parapet may include significant additional loads, basically vertical and horizontal, applied to the bridge deck directly by the wheels of the vehicle and by friction of barrier elements leaning on the deck.

Having the results of the initial type testing tests and of the push pull tests, the time history of all the loads generated by the collision can be determined with Computational Mechanics, using validated simulations.

4.2.2.3.2 Validation of initial type testing simulations

Only the use of a validated containment test simulation is appropriate and EN 16303 contains minimum requirements for the necessary validation.

In addition, it is appropriate to compare the load deflection curve of the anchored elements with the one measured in dynamic push pull tests or with the one measured in static push pull tests incremented by the rheological effect, verifying that the curves have the same trend and that the peak values do not differ by more than ±15 % of the push-pull test measurement.

4.2.2.3.3 Collision loads from validated computational mechanics

From the simulation validated as in 4.2.2.3.1, the time history of all the loads acting on the bridge deck during the collision can be obtained and used to elaborate all the information needed by the design of the bridge structure.

4.2.2.3.4 Normalised collision load

To take into account material quality of the test specimen, a normalisation factor might be calculated according to Annex B.

4.2.3 Determination of collision forces by measurement during the initial type testing

4.2.3.1 General

It is of great importance to avoid damage occurring to the main bridge structure as a result of a vehicle collision with a vehicle restraint system installed on the bridge. Thus, the collision design forces represent an ultimate load case for the VRS.

A specific safety factor for the measured forces can be estimated by independent expert assessment to take possible residual strength of the VRS into account.

4.2.3.2 Description of testing device

4.2.3.2.1 General testing requirements

EN-1317-1 and EN 1317-2:2010 contain the requirements that have to be fulfilled.

During the heavy vehicle test, it is desirable to measure the collision forces, the impact point being in the middle of the test sample length equipped with force measurement instruments.

4.2.3.2.2 Specific testing requirements to measure impact forces

The system of measuring has to include the stress of the main construction, as well as the anchoring forces of the bridge cap, if present. The following gives well-proven test conditions for the simulation of bridges made of concrete. The results can be transferred to steel bridges but the individual local bridge stiffness and the different anchorage conditions have to be taken into account.

a) Typical Layout (see Annex C)

1) Area of Measurement

A minimal total test facility length of 12 m, and consisting of independent units not longer than 4 m bearing on suspension devices, is needed.

It is appropriate to measure all support reactions of the suspension devices, with the suspension devices arranged in such a way that the individual values (to determine the internal forces M, N and V) (see 4.2.1.2.2) can be measured per static determined bearing.

A mass of at least 1250 kg / m for the independent units is required.

2) Bridge Cap

If the installation of the VRS is foreseen on a bridge cap, the bridge cap can be provided for the total length of the test device and be divided like the independent measuring units, or the cap length might be extended continuously. It is possible to transfer the result of one measurement to the other (continuous or divided cap), but it has to be specified in national regulations if and under which conditions both or only one kind of measurement is accepted.

A minimum width of the cap of 1,25 m is appropriate. National requirements can ask for a wider width (e.g. in Germany ≥2,0 m).

It is appropriate to design the cap thickness in such a way as to ensure that the concrete cover is at least 2 cm between anchor borehole and underside of cap (e.g. in Germany: borehole depth ≤13 cm).

A bridge cap with a mass of at least 900 kg/m is appropriate.

It is appropriate that a minimum width of 0,90 m of the bridge cap fully rests on the measuring elements with an e.g. 5 mm waterproofing membrane in between to reproduce realistic friction behaviour.

b) Measurement Specifications

The sampling rate has to be at least 10 kHz (12 bit resolution).

It is appropriate to apply filter class CFC 1000, according to ISO 6487.[2)]

The data have to be provided in ASCII – format.

2) Use of CFC 180 for structural design.

c) Determination of collision forces

1) General requirements

Measurement length, equipment and results, as described in section a) and b) are required in order to determine the collision forces.

2) Bridge cap

The measuring devices must be arranged in such a way that two horizontal forces (to determine the resulting values of H and M between bridge cap and cantilever slab) can be measured per 0,80 m length of the bridge cap at least along the test facility length.

3) Bridge structure

The sum of forces of each suspension device in each independent unit and the total sum for all units are evaluated taking into account the actual time they occur.

4) Evaluation

Detailed procedures of how to transfer the measurements to characteristic loads have to be defined in national specifications as the load classes according to EN 1991-2 are also to be defined by each member country. Examples for such procedures are given in Annex D.

The measured internal forces in the units obtained from the suspension device measurement taking into consideration the actual time they occur can be transferred to resulting horizontal and vertical forces and bending moments. These forces (and bending moment) can occur at different times and all time frames are to be checked.

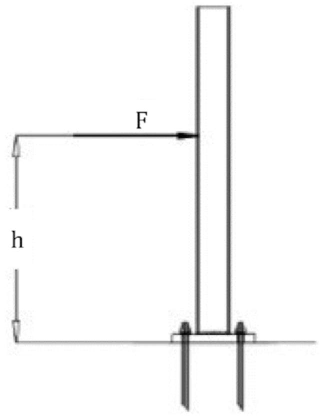
Annex A
(informative)

Comparison of test measurements and calculation

This Annex provides data measured in Italy, in push-pull static and dynamic tests on barrier posts anchored to bridge decks.

This data is provided to allow comparisons with the ones from calculations.

The test has been performed on 9 posts of 3 types, as shown in Table A.1. The height of the applied load, indicated in Figure A.1 is not the same for the different post types, as reported in Table A.1.



Key

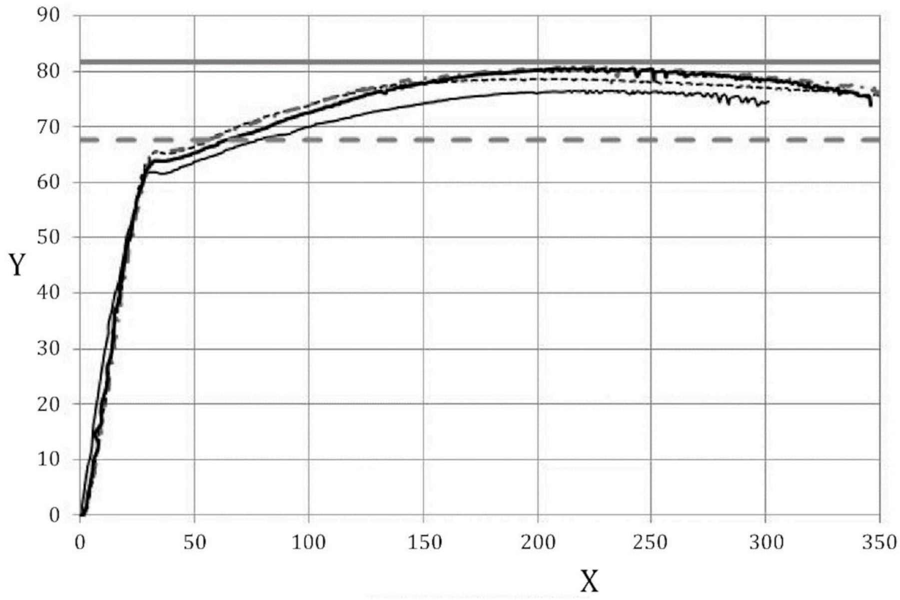
h Height of load

F Applied force

Figure A.1 — Height of load

Table A.1 — Test reported

Post profile	N. of posts	Post code		Material	Type of test	Height of load (m)
HE120B	4	C1, C2, C3, C4		S275JR	Static	1,00



Key

———	Post C1
······	Post C2
— · —	Post C3
———	Post C4
———	Realistic Ult Stress
– – –	Realistic Yield stress
X	Displacement (in mm)
Y	Moment (in kNm)

Figure A.2 — Posts C - Comparison with calculation (realistic stresses)

In Figure A.2, the moments from measurements are compared with the ones computed above with realistic values of yield and ultimate stresses.

The static measurement on posts C (Figure A.2) is in very good agreement with the computed yield and upper limit moments.

Annex B
(informative)

Normalised collision load

If the post gives way first during the test, the individual results are multiplied by

$$\frac{f_{\text{u,post.max}}}{f_{u.post\ measured}}$$

where:

$f_{\text{u,post.max}}$ is the guaranteed upper limit for the tensile strength of the grade of steel used for the posts, as determined in EN 10025-2 (e.g.: for steel grade S235, $f_{\text{u.max}} = 510\ N / mm^2$)

$f_{u.post\ measured}$ is the measured tensile strength of the posts used during the tests.

If the anchor gives way first during the test, the individual results are multiplied by:

$$\frac{f_{\text{u, anchor.max}}}{f_{u.anchor\ measured}}$$

where:

$f_{\text{u,anchor.max}}$ is the guaranteed upper limit for the tensile strength of the anchors

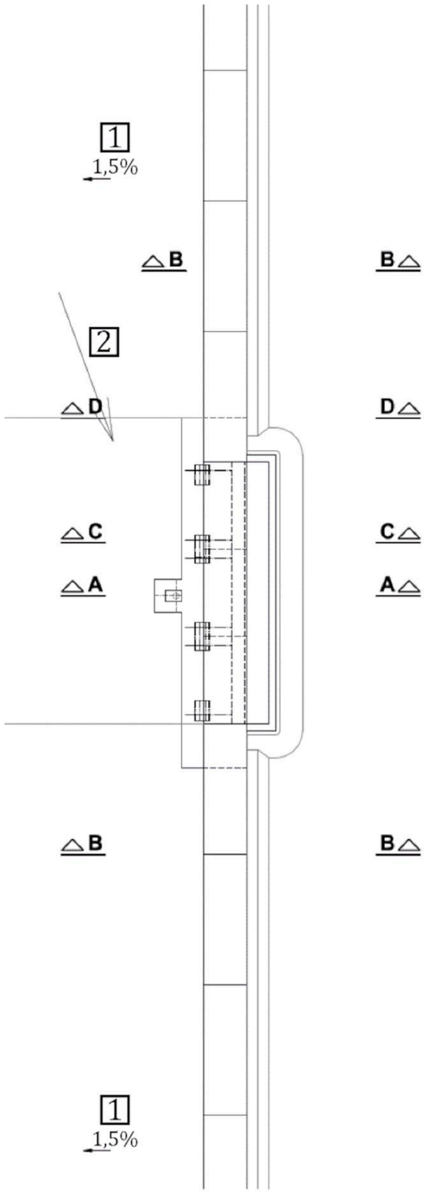
$f_{u.anchor\ measured}$ is the measured tensile strength of the anchors used during the tests

Annex C
(informative)

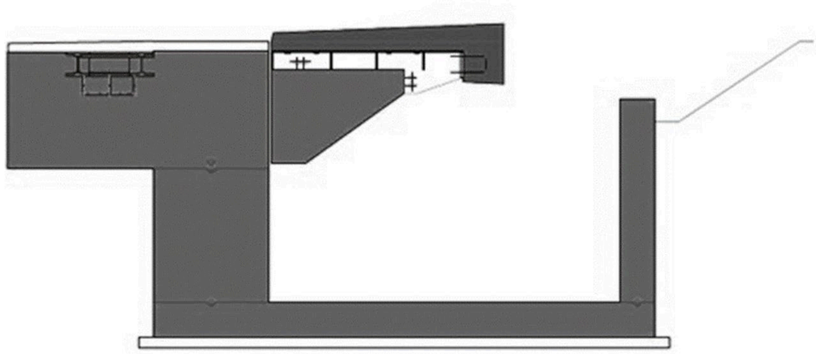
Description of the typical layout of test facilities and Measurement specifications

C.1 Layout of test facility

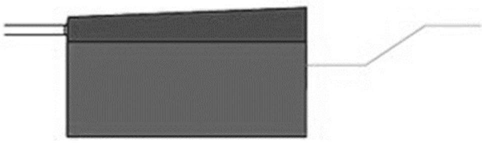
The layout of a typical test facility is given in Figure C.1.



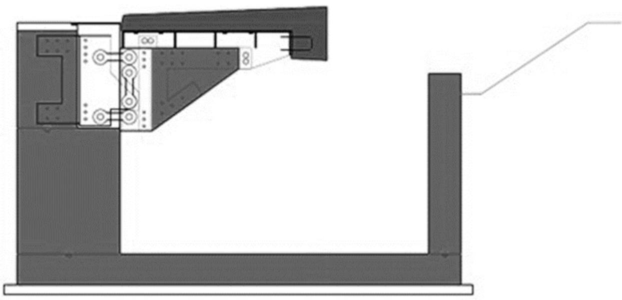
a) Overview



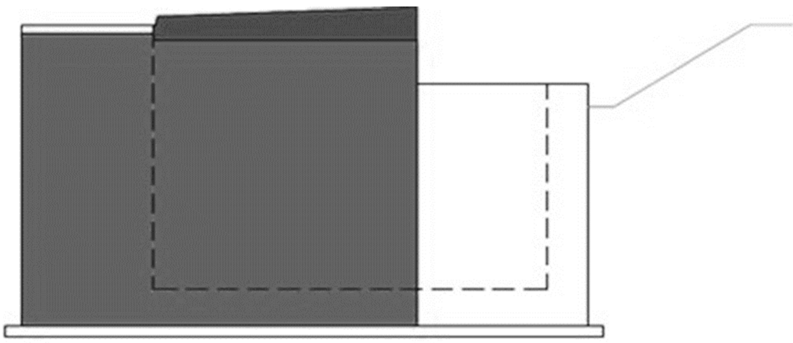
b) Section A –A



c) Section B – B



d) Section C –C



e) Section D – D

Key

1 Asphalt

2 Approach direction

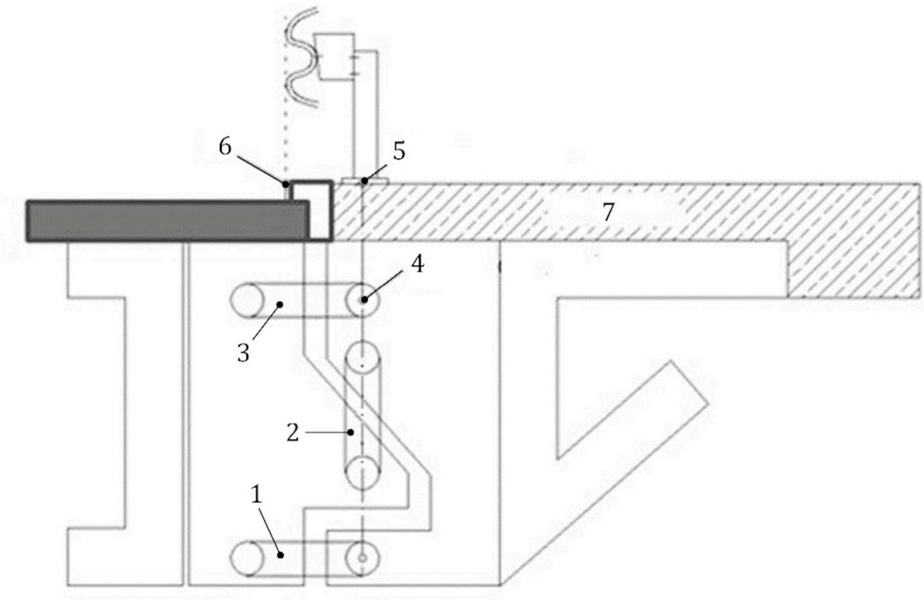
Figure C1 — Layout of a typical test facility

Each of the 3 single 4 m cantilever units in the 12 m long test facility is constructed as a cantilever. Each of the cantilever units is supported by six eye bars as suspension devices. For each single cantilever element thus 6 values must be recorded. Overall, provided the test facility consists of three single cantilever elements, thus 18 measured values must be determined. The bridge cap can be foreseen continuously or divided.

C.2 Measurement equipment of the Cantilever slab

The three cantilever slabs are fixed on the lateral concrete wall each by two suspension devices. Each suspension device has three eye bars equipped with strain gauges. During the impact, all 18 eye bars forces are recorded with a rate of 10 kHz. The internal forces of each suspension device can be calculated by simple operations due to the arrangement of the bars taking into consideration the actual time it occurs (see Figure C.2).

The reference point of the internal forces is the point of intersection of the axis of the vertical bar and the axis of the upper bar (reference point 1). For designing the cantilever slab of a bridge the upper interior edge of the edge beam is chosen as reference point (reference point 3). The horizontal normal force acting on one suspension device is the sum of the force in the lower bar and the one in the upper bar. The measured force in the vertical eye bar is the vertical force acting on this suspension device. The bending moment of this suspension device is the product of the force in the lower bar and the distance between of the axis of the vertical and the axis of the upper bar (in relation to reference point 1) of a cantilever element.



Key

1 Eye bar 1

2 Eye bar 2

3 Eye bar 3

4 Reference point 1

5 Reference point 2

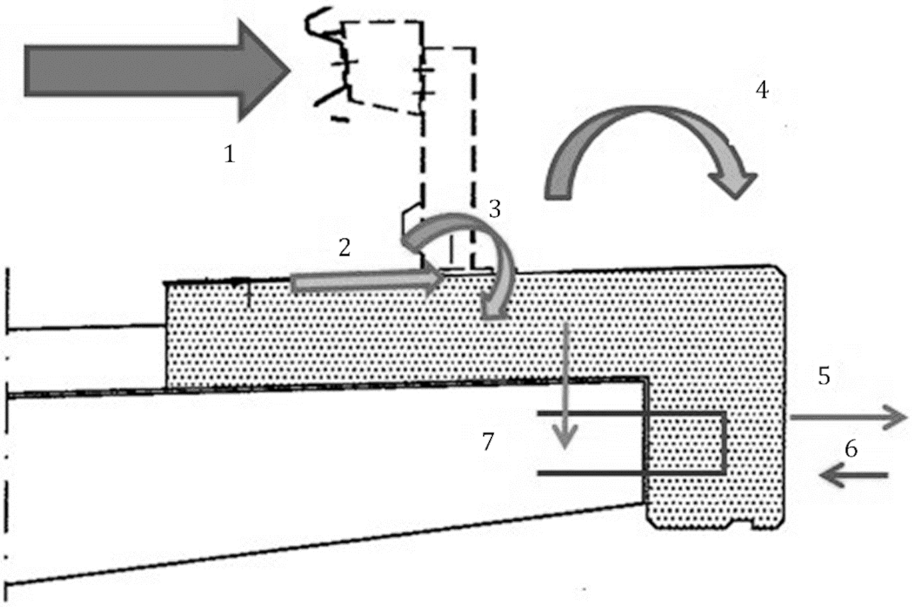
6 Reference point 3

7 Edge beam

Figure C.2 — Arrangement of suspension devices

C.3 Measurement equipment of the Bridge cap

In the case of an accident when a HGV hits the restraint system a moment is created which wants to uplift the bridge cap. This moment has to overcome at first the self-weight of the edge beam itself to activate the upper horizontal anchor (see Figure C.3).



Key

1	LKW	5	$H_{Anchor, up}$
2	H	6	$H_{Anchor, down}$
3	M	7	$G_{Bridge\ cap}$
4	Overturning moment		

Figure C.3 — Internal and external forces due to collision loads on a bridge deck

The overturning moment for the 12m testing pit in the result of $G_{Bridge\ cap}$ and $H_{Anchor,up}$ forces is computed with a reference to the point of rotation between the edge beam and the cantilever.

Annex D
(informative)

Comparison of methods to determine characteristic loads from measurements

D.1 General

The subsequently described methods to determine characteristic loads refer to measurements done in a test facility according Annex C.

For procurement by tender it is reasonable to classify VRS for bridges according to their load level. From the determined characteristic loads a load classification can be derived following one of the two described procedures below. Since bridges in Austria and Germany are equipped with bridge caps both methods take bridge caps into account.

In BASt report 138, a comparison of the two methods is given.

D.2 Austrian approach

D.2.1 Bridge cap

Since the load is not equally distributed over the 12 m, the overturning bending moment and the total horizontal force, obtained by measurement according to section 4.2.3.2.2 c, 2, are transferred to forces and moments. acting on a certain number of VRS posts or anchorages at the same time.

Therefore sum of anchor forces measured in each slab, in two neighbouring slabs and the total sum are evaluated. Therewith the related total horizontal forces ($H_{total} = H_{Anchor,up} + H_{Anchor,down}$) and the overturning moment are to be considered according AnnexC, Figure C.3, taking into account the actual time they occur (Force /Time).By distributing this measured forces to the to the VRS posts or anchorages of the affected area a maximum load can be determined.

This load combination (M and H$)$ has to be applied on a number of anchorages simultaneously. This number has to be determined by assessing the VRS deformation during the type test; e.g. deformation of posts, broken anchorages have to be taken into account.

E.g. when for the deformation length of 8m a number of three anchorages has to be taken into account the maximum total forces of two neighbouring slabs are transferred to anchorage - loads in such way:

$$H = \frac{H_{total}}{3}$$

$$M = \frac{M_{overturning}}{3}$$

Applying these loads the bridge cap itself and the connection between bridge cap and bridge structure has to be designed.

D.2.2 Bridge structure

D.2.2.1 General

For each independent unit the time history of the total internal forces (sum of two suspensions) *H, V, M* referring to reference point 1 and 3 is calculated (example is given in Table D.1). The force combinations for H_{max}, V_{max} and M_{max} have to be evaluated for each independent unit as well as the max sum of two neighbouring units. The highest single forces acting at different time frames are determined as characteristic loads.

D.2.2.2 Determination of design forces

A nationally entitled entity determines a characteristic load combination. Taking into account the residual strength of the system an additional safety factor f_{res} is determined individually. This result is transferred in a characteristic load combination h, v, and m acting on reference point 3 as 4m distributed loads.

Table D.1 — Example of highest experimental forces according 4.2.3.2.2 c) 3.

Slab	M_{max} [kNm] Ref. pt. 1	M_{max} [kNm] Ref. pt. 3	H_{max} [kN]	V_{max} [kN]
slab 1	18,37	21,85	-10,58	2,72
slab 1	-3,51	-29,52	38,96	31,85
slab 1	11,58	6,27	-14,70	35,99
slab 2	56,66	34,96	34,11	24,49
slab 2	37,52	14,34	41,57	19,47
slab 2	10,44	-15,82	24,03	52,10
slab 3	203,65	108,28	70,59	210,89
slab 3	135,42	72,63	109,28	57,10
slab 3	201,37	103,83	58,39	217,79
slab 2+3	217,41	118,80	99,38	183,69
slab 2+3	190,23	109,30	131,18	86,18
slab 2+3	212,85	112,40	79,82	215,00
slab 1+2+3	223,93	115,88	89,87	226,03
slab 1+2+3	190,73	76,04	136,74	186,11
slab 1+2+3	218,71	113,16	78,43	232,99

In slab three the highest forces in a single slab were measured; also by taking into account the distributed force combinations of two slabs and all three slabs.

Since in the impact area the anchoring bolts did not break and the main components reached only elastic deformation f_{res} =2,0 was determined.

$M_{3\,exp}$ = 108,83 kNm rounded up to M_3= 110 kNm distributed to m = 110/4*2,0 = 55 kNm/m

H_{exp} = 103,8 kN rounded up to *H*= 104kN distributed to h = 104/4*2,0 = 52 kN/m

V_{exp} = 217,8 kN rounded up to *V*= 220 kN distributed to v = 220/4*2,0 = 110 kN/m

Especially for existing bridges being refurbished or just upgraded with new restraint systems these design forces can be used directly as accidental load. The partial safety factors for the permanent loads and the collision forces are 1,0. The load case “collision on restraint system” has to be considered as a single load case. Therefore other variable loads from road traffic, wind and snow, earthquake loads and other accidental loads do not have to be considered in combinations which include collision on restraint systems.

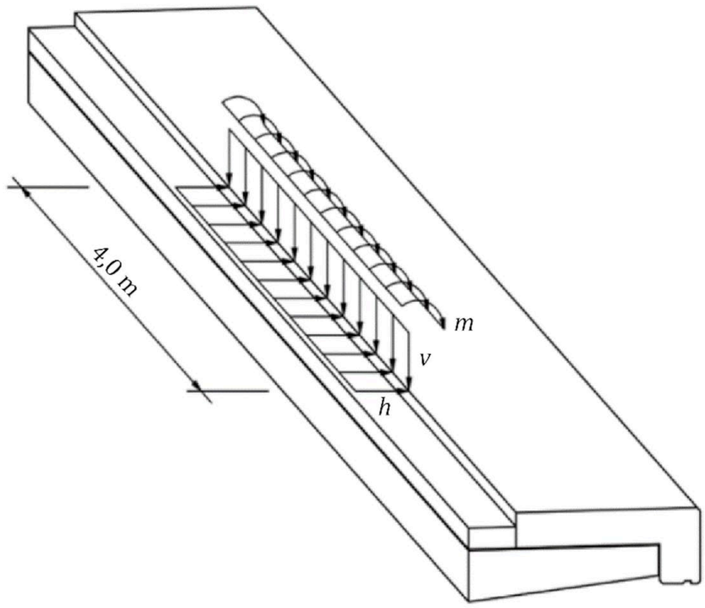
D.2.2.3 VRS classification

In EN 1991-2 it is foreseen that each country can define load levels in their National Annex. These national load levels for Austria are defines in Table D2:

Table D.2 gives the classes defined in Austria.

Table D.2 — Recommended classes for VRS in Austria

Impact Class	*h* Horizontal Load kN/m	ν Vertical Load kN/m	Moment ***m*** N/m
EK 1	50	50	45
EK 2	67	67	60
EK 3	110	110	99
EK 4	150	150	135



Key

m moment

ν vertical load

h horizontal load

Figure D.1 — Application of 4 m distributed accidental load

To classify a system the characteristic load of that system has to be applied on a bridge structure. The stresses have to be compared with the stresses obtained by applying the load according to the load classes to a standard bridge cantilever with 2,0m length and 0,3m thickness:

	σ_{max} (kN/m^2)
EK1	0,88
EK2	1,06
EK3	1,53
EK4	1,96

Example σ_{max} = 1,29 kN/m

The classification of the VRS-example according to section D 2.2.2. therefore is EK3.

D.3 German approach

D.3.1 Bridge cap

The local characteristic loads of VRS are determined by using the analytical approach in chapter 4.2.1.6 and 4.2.1.7 in order to design the bridge cap and the connection between cap and structure.

It is appropriate to take into account the resulting values of measured forces between bridge cap and cantilever slab in order to check the analytical results.

D.3.2 Bridge structure

D.3.2.1 General

Based on EN 1991-3 a method for classification of impact loads of safety barriers was developed. In EN 1991-2 some boundary conditions have changed, so that the method has to be amended.

As a result of the evaluation in 4.2.3.2.2 c, 2, the maximum normal forces for each 4 m block (unit) and for the whole 12 m measuring bridge are available. The maximum horizontal and vertical forces occurring in the 4 m block and in the overall system are then identified.

D.3.2.2 Horizontal

For system classification a calculated auxiliary parameter H_H has to be compared against the defined load classes.

Table D.3 — Recommended classes for VRS in Germany

Recommended Class	H [kN] horizontal force
A	100
B	200
C	400
D	600

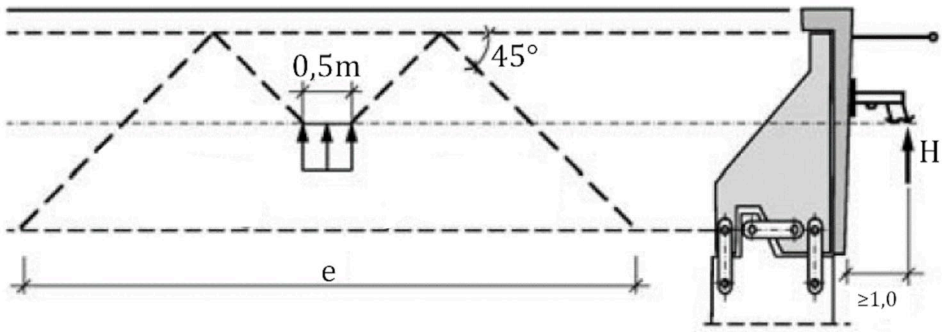
$$H_H = H_{max,unit} + \left((e - 4\ m) \times \frac{H_{max,sum12m}}{12m} \right)$$

where

$H_{max,unit}$ is the maximum measured horizontal force of one 4 m unit

$H_{max,sum12m}$ is the maximum measured sum of horizontal forces on a 12 m length (all 3 units)

e is the load distribution at fixed cantilever support dependent on the location of test system in the type test and the system geometry according to Figure D.2.



Key

H Horizontal force

Figure D.2 — Evaluation of load distribution length e

To determine the auxiliary parameter which is decisive for the grading into horizontal load classes, the following is presumed. Depending on the position of the safety barrier on the cap during the test, the safety barrier "as a model" is fixed rigidly to the cap and the cap itself is fixed rigidly to the cantilever at its edge. It is assumed that the horizontal force and the bending moment are distributed by an angle of 45° (Figure D.2).

The resulting load distribution length e is found along the support line (see Figure D.2, generally approx. 4 to above 6 m, depending on position of safety barrier). Using length e, the critical auxiliary parameter can be calculated with the maximum share of the 4 m block. The remaining length e – 4 m uniform load share of the 12 m complete system (CS) is added. Comparing these with the horizontal forces of classes A to D leads to the relevant classification.

Example:

- 4 m block max.: 110 kN resp. 27,5 kN/m
- *e* = 5,96 m
- 12 m *CS max*.: 168 kN resp. 14 kN/m

Calculated auxiliary parameter

= 110 + (5,96 - 4) * 14 = 137.4 kN

Maximum *Cl. A* = 100 kN < 137,4 kN ≤ 200 kN = *Cl. B*

Therefore, Classified into Class B

D.3.2.3 Vertical

Due to the non-existent shear force coupling of adjacent console elements (only the cap being monolithic throughout a length of 12 m in longitudinal direction), the measured forces are averaged and smoothed in order to calculate the auxiliary parameter for the determination of the decisive vertical force.

The vertical maximum uniform load over the block length of 4 m and the proportionally over the remaining length of 8 m evenly distributed maximum vertical force are averaged and applied to a 4 m block.

Normally the maximum value relating to the complete 12 m system is larger than the maximum value of the 4 m block. In the exceptional case that this is not true, the vertical force share of the remaining 8 m length will be set to zero. The decisive vertical force derived by the aforementioned averaging will then be half the maximum value of the 4 m block.

$$V_H = 0,5 \times \left(\frac{V_{\max unit}}{4m} + \frac{\left(V_{\max sum\,12m} - V_{\max unit}\right)}{8} \right) \times 4m$$

The minimum value of vertical force as determined in EN 1991-3 is considered to be V = 075 * α_{Q1} * Q_{1k} (=180 kN of α_{Q1}=0.8)

Example:

- 4 m-block max.: 368 kN therefore. 92 kN/m
- 12 m CS max.: 640 kN

Calculated auxiliary parameter

= 0,5 * [368/4 + (640 - 368)/8] * 4 = 252 kN > 180 kN

therefore, increase of vertical force necessary by factor 252/180 = 1,4

Example:

- 4 m block max.: 312 kN / 4 m = 78 kN/m
- 12 m *CS max*.: 298 kN

Calculated auxiliary parameter

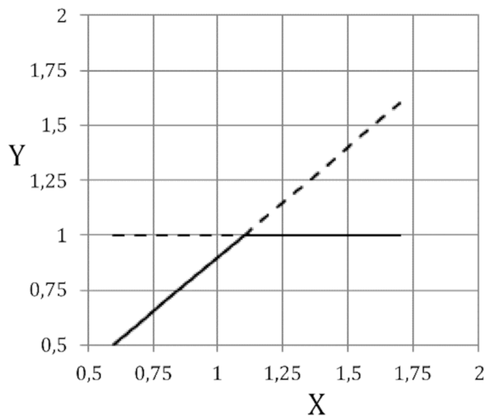
= 0,5 * 312 = 156 kN < 180 kN

therefore, decisive is V = 180 kN

An increase of vertical force is not necessary. Factor = 1,0

Following the introduction of EN 1991-2, two adjustments were necessary:

- acting point of H (see Figure D.3)
- α_{Q1}=1,0 instead of 0,8 (V = 075 * α_{Q1} * Q_{1k} =225 kN)



Key

———	EN 1991-2
– — –	EN 1991-3
X	Height of vrs above cap surface (in m)
Y	Point if horizontal load application above cap surface (in m)

Figure D.3 —Difference of acting point between EN 1991-3 and EN 1991-2

For safety barriers with Factor = 1,0 or close to 1, the potential reduction of the lever arm at high systems is compensated by the increase of the vertical force V = 225 kN. For safety barriers with Factor ≥ 1,25 or close to 1,25 and with lever arm more than 1 m, deviating from the limitation in EN 1991-2 the lever arm has to be kept. An alternative method of determining the lever arm is a comparative analysis at a short cantilever arm (1,50 m) to a value ≥ 1,0 m, which must be at least equal to the same bending moment at the cantilever fixation in accordance with EN 1991-3.

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