Swiss Federal Roads Authority (ASTRA)
Swiss Association of Road and Transportation Experts (VSS)

Design and Verification Concepts for Anchorages of Road Restraint Systems on Bridge Decks

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Im Rahmen einer Revision der Norm EN 1317-2, Rückhaltesysteme an Strassen - Teil 2: Leistungsklassen, Abnahmekriterien für Anprallprüfungen und Prüfverfahren für Schutzeinrichtungen, sind die normativen Grundlagen zur Bemessung der Befestigung von Schutzeinrichtungen zu schaffen. Der Bericht enthält dazu die wissenschaftliche Basis. Die Bearbeitung erfolgte im Rahmen des Mandates des Delegierten der Schweiz in der Arbeitsgruppe CEN/TC 226/ WG 1.

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Contents

1 Introduction

1.1 Scope

In this paper design and verification concepts for the anchorage of road restraint systems on bridges are introduced. The concepts are based on both load and capacity criteria. However, the main objective of the presented concepts is to establish appropriate design and verification procedures for anchorages on edge beams to prevent any damage on the structural members of the bridge in case of a vehicle impact. Therefore, partial safety factors are specified, which may be used for the determination of the design actions needed for the design and verification of the structural safety of edge beams of bridges.

1.2 Terms relating to anchorages

As illustrated in Figure 1, every connection to concrete is composed of the following basic components:

– The attachments (e.g. guardrail posts), which are connected to the structural unit (edge beam of the bridge). They are usually of steel and include fixtures (baseplates)

– The anchors themselves (e.g. bonded anchors or cast-in-place anchor systems), which attach the fixture to the concrete respectively the edge beam of the bridge

– The embedment or the base material, consisting of the concrete surrounding the anchors.

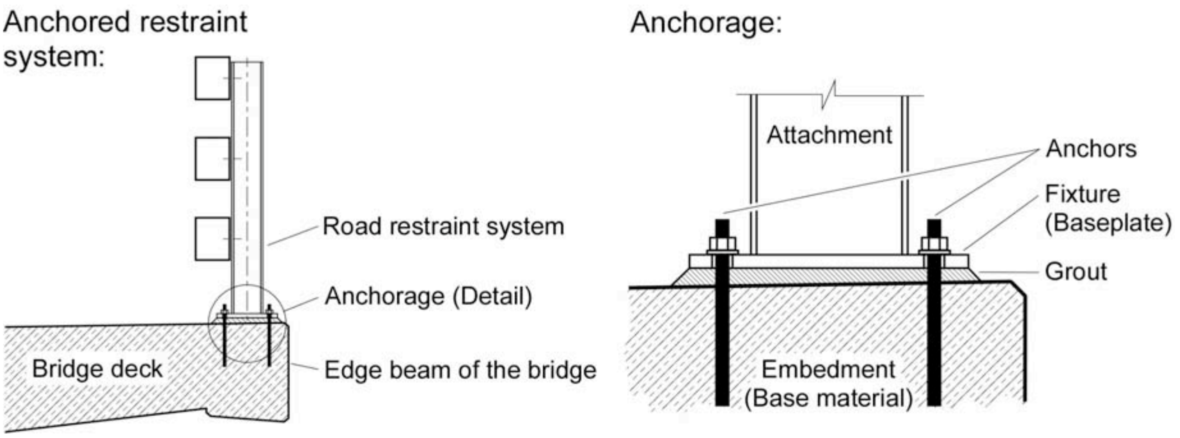


Figure 1: Basic anchorage nomenclature

1.3 Notation

Latin upper case letters

F	Force
F_d	Design value of an action
$F_{d,y}$	Design value of an action in y-direction (perpendicular to traffic)
F_k	Characteristic value of an action
M_d	Design value of the acting momentum
$M_{k,AC}$	Calculated characteristic momentum of the attachment respectively momentum according to a single loading test
M_{IT}	During impact test measured anchoring momentum
$M_{k,BC}$	Calculated characteristic value of the breakaway momentum
N_d	Design value of the acting tension load
$N_{k,AC}$	Calculated characteristic tension load of the attachment respectively tension load according to a single loading test
N_{IT}	During impact test measured anchoring tension load
$N_{k,BC}$	Calculated characteristic value of the breakaway tension load
P	Probability
R_d	Design value of a resistance
R_k	Characteristic value of a resistance
V_d	Design value of the acting shear load
$V_{k,AC}$	Calculated characteristic shear load of the attachment respectively shear load according to a single loading test
V_{IT}	During impact test measured anchoring shear load
$V_{k,BC}$	Calculated characteristic value of the breakaway shear load
X_k, Y_k	Characteristic value of the variable X, Y
X_m, Y_m	Mean value of the variable X, Y
$X_{5\%}$, $Y_{5\%}$	5%-Fractile of the variable X, Y
$X_{95\%}$, $Y_{95\%}$	95%-Fractile of the variable X, Y

Latin lower case letters

m	Mean value
n	Number of tests
s	Standard deviation
s_X, s_Y	Standard deviation of the variable X, Y
k	Statistical factor in accordance to Owen [7]

v	Coefficient of variation
v_i	Coefficient of variation for the variable i
v_{AC}	Coefficient of variation for the attachment capacity
v_{BC}	Coefficient of variation for the breakaway capacity
v_{bf}	Coefficient of variation concerning to bolt failure
v_{dd}	Coefficient of variation for beams in bending concerning dimensional deviations
v_{ia}	Coefficient of variation for impact test conditions concerning the impact angle
v_{is}	Coefficient of variation for impact test conditions concerning the impact speed
v_{IT}	Coefficient of variation for the results of impact tests
v_{mf}	Coefficient of variation for beams in bending concerning model-factors
v_{mp}	Coefficient of variation for beams in bending concerning material properties
v_{tc}	Coefficient of variation for the impact test conditions
v_{to}	Coefficient of variation for the impact test object (restraint system)
v_{tv}	Coefficient of variation for the impact test vehicle
v_{vm}	Coefficient of variation for impact test conditions concerning the vehicle mass
v_{wf}	Coefficient of variation for welding joint failures

Greek lower case

γ_{AC}	Partial factor for the attachment capacity
γ_{BC}	Partial factor for the breakaway capacity
γ_F	Partial factor for actions
γ_{IT}	Partial factor for impact test results
γ_M	Partial factor for a material or product property
γ_s	Partial factor for scatter

2 Distribution of design variables

2.1 Basics

Variables used for the design and verification of anchorages normally have some scatter. That means, that it is not accurate calculating with deterministic values. It should be noted therefore, that for an appropriate description of a design variable, more information is needed. The complete specifications for such a random variable generally are given by

– Type of distribution (e.g. Normal, Lognormal, Extreme value)

– Mean value, m

– Standard deviation, s

– Skewness (for distributions which are not symmetrical)

Figure 2, schematically shows the distribution functions for the two normal distributed variables X and Y with the same mean value ($X_m = Y_m$) but different scatter, expressed by the different standard deviations s_X and s_Y. It should be pointed out, that the representative or so-called characteristic values X_k and Y_k, normally used for design and verification, have considerable different values.

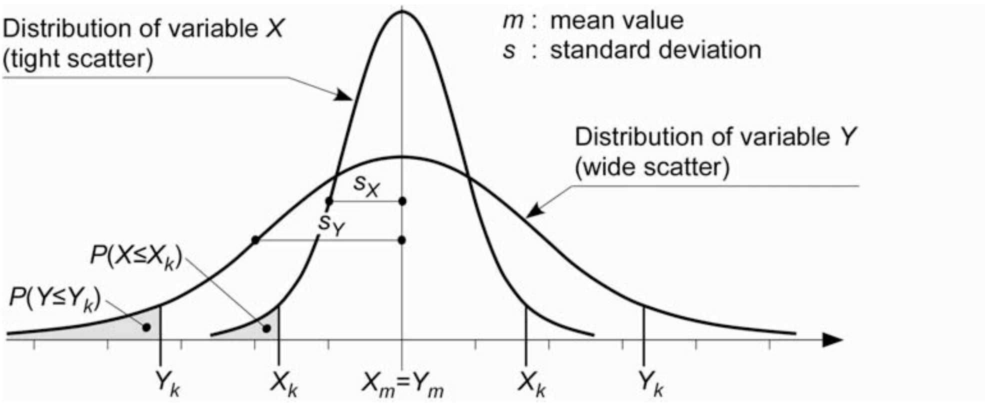


Figure 2: Schematic graph of the distribution of variables with different scatter

The scatter describing the wide of a distribution can also be expressed by the coefficient of variation which is defined as follows:

$$v = \frac{s}{m} \tag{1}$$

where:

s Standard deviation of the variable

m Mean value of the variable

The scatter of a variable often depends from the scatter of a great number of other random values. For example, the scatter of the bending resistance of a steel beam is depending from the uncertainties concerning the material properties (e.g. yield stress) as well as from the uncertainties concerning the dimensional deviations. In such a case the coefficient of variation has to be calculated as follows:

$$v = \sqrt{\sum_{i=1}^{n} v_i^{\,2}} \qquad (2)$$

where:

v_i coefficients of variation for the variables $i = 1, 2 \dots n$

2.2 Partial factor for scatter

For both, resistance and action variables normally the 5%- respectively the 95%-fractile are used as the representative or characteristic values X_k. This implies, that the probability P that the value of a random variable is smaller respectively higher than the characteristic values is only 5%. ($P \leq 0{,}05$).

For Normal distributions the 5%- and the 95%-fractile are in accordance to Owen [7] as follows:

$$X_{5\%} = X_m - k \cdot s_X \qquad (3)$$

$$X_{95\%} = X_m + k \cdot s_X \qquad (4)$$

where:

X_m Mean value of the variable X

s_X Standard deviation of the variable X

k Factor in accordance to Owen [7]
k = 1,645 for Normal distributions

The presented design concepts according to impact tests (Section 5) as well as the capacity design methods (Section 6 and 7) are based on the difference between the 5%- and the 95%-fractile (Figure 3). For this reason, the partial factor for scatter γ_s is defined as the ratio of the fractiles:

$$\gamma_s = X_{95\%} / X_{5\%} \qquad (5)$$

where:

$X_{95\%}$ Value of the 95%-fractile of the variable X

$X_{5\%}$ Value of the 5%-fractile of the variable X

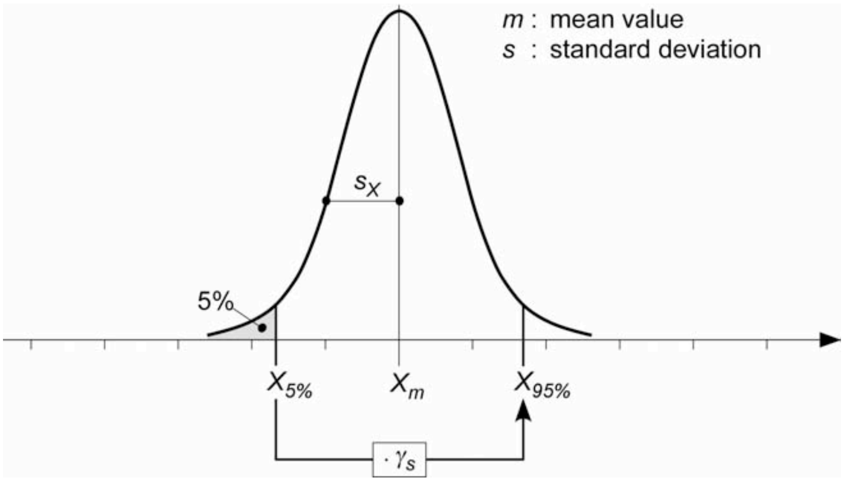


Figure 3: Definition of the partial factor for scatter γ_s

Replacing the standard deviation s_X with the expression $X_m \cdot v$, where v stands for the coefficient of variation and setting in equation (3) and (4) in equation (5) lead up to the following formula for the partial factor for scatter:

$$\gamma_s = (1 + k \cdot v) \;/\; (1 - k \cdot v) \qquad (6)$$

where:

v Coefficient of variation of the distribution

k Factor in accordance to Owen [7]

The function of γ_s for the Normal distribution with the factor $k = 1{,}645$ is plotted in Figure 4. It should be noted, that the partial factor is increasing heavily with an increasing coefficient of variation, what means, that it would be very large, when the scatter of the variable is wide.

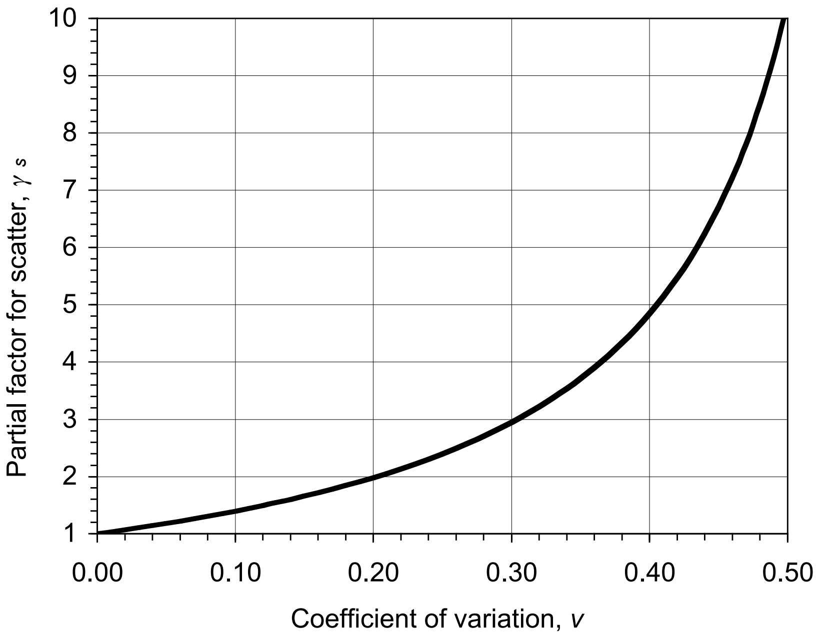


Figure 4: Value for the partial factor for scatter γ_s, depending on the coefficient of variation

2.3 Principles of capacity design

The capacity design of anchorages is based on the fact, that the anchor loading is depending on the loading transferred by the attachment. The maximum possible anchor loading cannot exceed the load, leading to a failure of the attachment. Therefore, the action used for the verification of the structural safety of the anchorage may be assumed equal or more than the resistance of the attachment in its ultimate limit state.

It is important to consider that both the resistance of the attachment and the resistance of the anchorage have some inherent uncertainties and therefore should be described in statistical terms. By using representative values and partial safety factors, structural design codes (e.g. Eurocodes) are taking into account these uncertainties. However, new design methods and verification concepts strictly separate actions and resistances. The design values for the action F_d and the resistance R_d are obtained from representative or characteristic values F_k and R_k (e.g. 5%-fractiles) with partial safety factors. The partial safety factors for the applied load γ_F and γ_M for material and product properties are covering uncertainties and scatter where loads and resistances are concerned.

Figure 5 shows the verification of structural safety for anchorages based on the bearing capacity of the attachment. There it should be verified that

$$F_d \leq R_d \tag{7}$$

where:

F_d Design value of the action acting on the anchorage

R_d Design value of the resistance of the anchorage

It should be noted, that using the maximum bearing capacity of the attachment as the anchorage loading not the 5%-fractile but that the upper characteristic value (e.g. the 95%-fractile) of the resistance has to be considered.

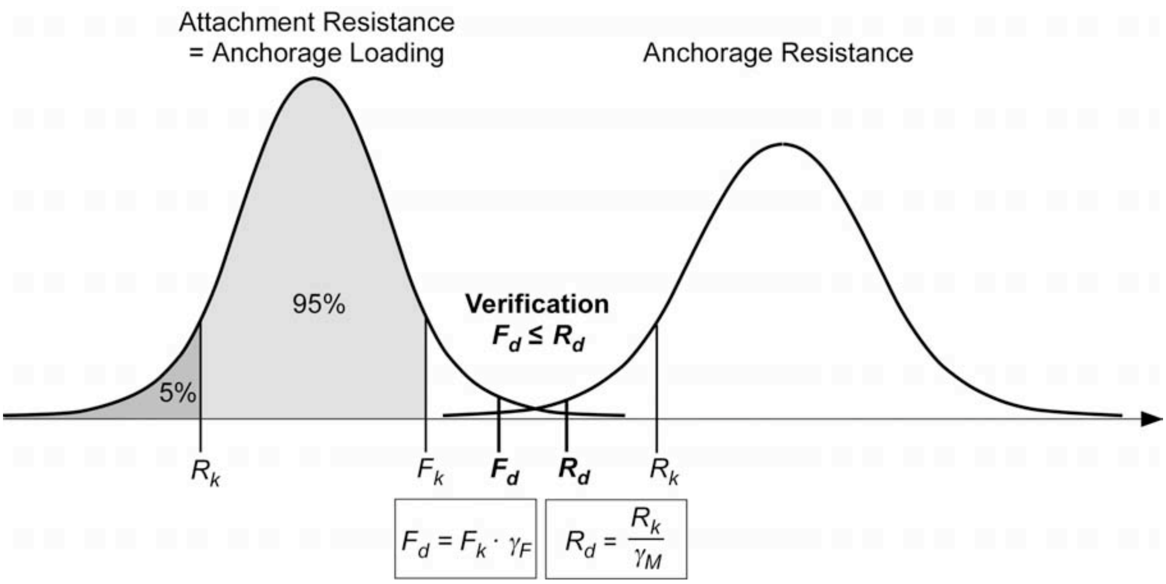
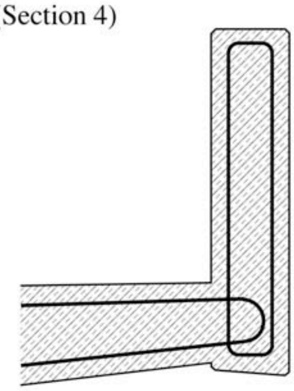
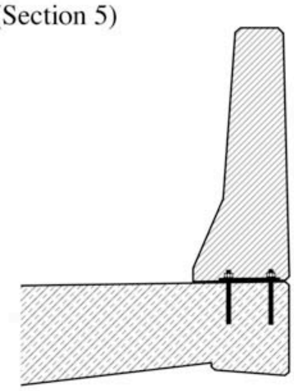
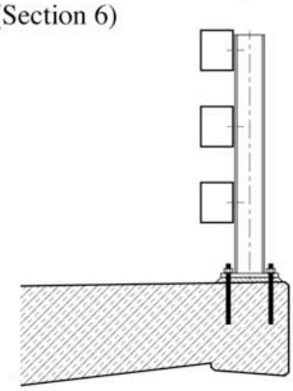
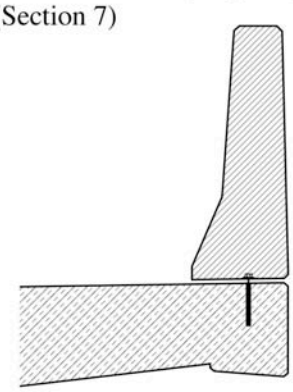


Figure 5: Verification of the structural safety of anchorages based on bearing capacity of the attachments

3 Overview restraint systems and anchorage

As an overview, Table 1 shows the construction possibilities of the edge beams of bridges with vehicle restraint systems. In general, four different possibilities concerning the deforming properties of the safety barrier in the case of a vehicle impact and the connection between the edge beam and the safety barrier are common respectively possible.

Table 1: Restraint systems and anchorage with corresponding design and verification methods

	Connection/anchorage of the road restraint system on the bridge deck		
	Restraint system is mono-lithic jointed (reinforced concrete structure)	Restraint system is anchored respectively rigidly fixed	Restraint system is not anchored or only fixed with rupture joint (breakaway)
Rigid safety barriers	Structural design according to **European/National codes** (Section 4) 	Anchorage design according to **impact testing** (Section 5) 	not common
Deformable safety barriers	not possible	Anchorage design according to the **attachment capacity** (Section 6) 	Anchorage design according to the **breakaway capacity** (Section 7) 

4 Structural design according to European and National codes

4.1 General

Reinforced concrete safety barriers, which are monolithic jointed with the bridge deck, have to be considered as entire structural systems. Therefore, the design and the verification of structural safety must be executed according to the European and National structural codes (e.g. Eurocodes).

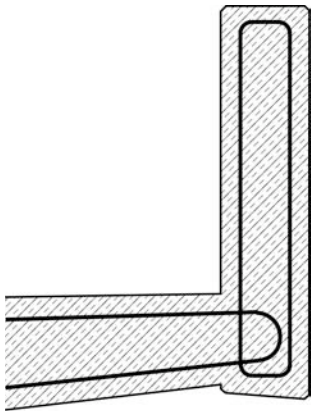


Figure 6: Rigid safety barrier, e.g. reinforced concrete vehicle parapet, which is monolithic jointed with the edge beam of the bridge

4.2 Accidental actions caused by vehicles

The actions presented in this section should be applied to structural elements in the vicinity of roads. These actions due to an impact caused by a vehicle are classified as accidental actions. For accidental actions the design value of the action is generally equal to the representative or characteristic value [1], [2]:

$$F_d = F_k \qquad (8)$$

where:

F_d Design value of an action

F_k Characteristic value of an action (e.g. value of the 95%-fractile)

Design Force due to vehicle impact on supporting substructures of bridges or other structures over roadways

For the case of a vehicle impact on vertical structural elements (e.g. columns) under bridges or other structures, Eurocodes [2], National standards (e.g. Swiss standards [4], [5]) or codes from organizations (e.g. UIC-Code [6]) are establishing horizontal static equivalent design forces due to impact. Depending on the type of road respectively the traffic speed as well as the type of vehicle, the design force perpendicular to the direction of normal travel according to [2] and [6] is as follows:

$$F_{d,y} = 500 \text{ kN} \qquad (9)$$

Design Force due to vehicle impact on safety barrier on the bridge

In Part 2-7, Eurocode 1 [2], the collision force on safety barriers on bridges is determined. For structural design, a horizontal force transferred to the bridge deck by rigid safety barriers should be applied. In accordance to [2] this force is as follows:

$$F_{d,y} = 100 \text{ kN} \qquad (10)$$

The impact force $F_{d,y}$ should be applied acting transversely and horizontally 100 mm below the top of the barrier or 1,0 m above the level of the carriageway or footway, whichever is lower (Figure 7). The force should be applied on a line 0,5 m long (Figure 8).

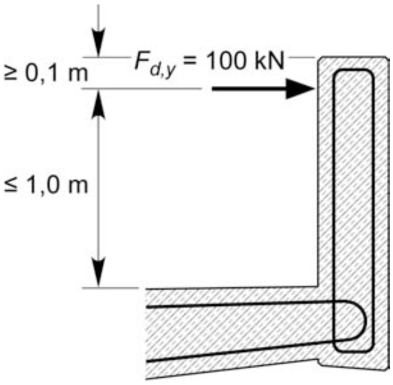


Figure 7: Collision force on safety barrier according to ENV 1991-2-7 (Eurocode 1, Part 2-7) [2]

4.3 Design and verification of the structural safety

The design and verification of structures should be executed according to the Eurocodes and/or the relevant National standards. The principles and requirements for structural safety described in the Eurocodes are based on the limit state concept used in conjunction with the partial factor method.

The basis of design and actions on structures are given in Eurocode 1 (ENV 1991) [1]. As mentioned above, the accidental loads due to vehicle impact are given in Part 2-7 [2]. Material properties (e.g. strength) and the partial factors γ_M for material or product properties are given within the design Eurocodes (ENV 1992 to 1999). For the design of concrete structures, Eurocode 2 (ENV 1992) is authoritative.

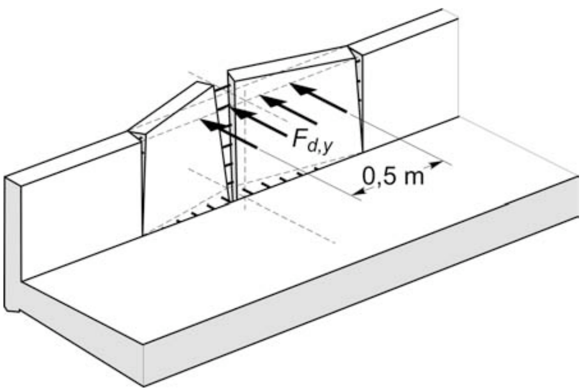


Figure 8: Example for an approach with the use of the shell theory for the structural design and verification of a rigid safety barrier transferring forces into the bridge deck

5 Anchorage design according to impact tests

5.1 General

Rigid safety barriers, e.g. concrete parapets but also steel guardrails with stiff posts and close post spacing, which are rigidly anchored on the bridge deck, can transfer heavy loadings into the edge beam of the bridge in case of a vehicle impact. The anchorage design as well as the verification of structural safety for the edge beam of bridges may be performed according to measurements of anchor forces during impact testing.

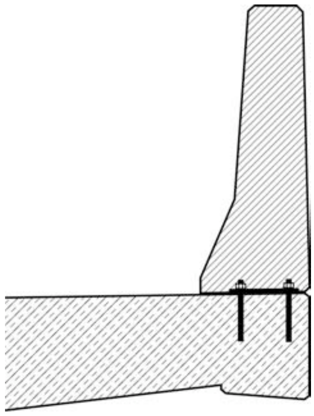


Figure 9: Rigid safety barrier, e.g. reinforced concrete parapet, which is anchored respectively rigidly fixed on the edge beam of the bridge

5.2 Design assisted by testing in general

Tests often are carried out to get information about the loading behaviour of the test specimen. In principal tests should lead to a statistical distribution for the prior unknown variables. Based on distributions, characteristic values may be derived. The characteristic value of a resistance normally is in accordance to the 5%-fractile obtained from ultimate loading tests.

Tests for example may be carried out with anchors in order to determine the characteristic anchor resistance. The 5% characteristic value should be calculated by Equation (3) in accordance to Owen [7]. The factor k in Equation (3) depends upon the number of tests n. For a confidence level of 90% the value of k is given in Table 2. It is obvious that the k-factor is decreasing with an increasing number of tests. Within this approach it is assumed that the standard deviation for both the population as well as the sample of test results are a priori unknown.

Table 2: Values of k depending on the number of tests n for the 5% characteristic value of a Normal distribution and a confidence level of 90% according to Owen [7]

n	1	2	3	4	5	10	20	50	100	∞
k	–	13,09	5,31	3,96	3,40	2,57	2,21	1,97	1,86	1,645

It is obvious that according to the provided a priori unknown distribution and the confidence level of 90% no k-factor exists for only one test. Therefore, it is also not possible to determine a 5% characteristic value with these assumptions. According to smaller confidence levels the values of k are generally smaller too. Nevertheless, without prior information concerning the distribution, it is not possible to determine the 5%-fractile.

If the distribution would be known a priori from pre-knowledge, it would be possible, based on Bayesian procedures, to determine a k value for only one test result. According to such procedures with vague prior distributions values of k are given in the informative Annex of Reference [1].

5.3 Approach for the determination of partial factors

As presented in Section 5.2 before, classical statistics as well as the theory of Bayes lead not to characteristic values when only single measurements and no prior information concerning to the distribution of the anchor forces during the impact tests are available.

The presented approach as follows is based on the assumption that the only available measurement is not a frequent respectively a mean value. In accordance to a conservative consideration it is predicted that the measurement would be a quite low but a probable e.g. a characteristic value. Regarding the measurement as a 5% characteristic value implies that an impact would achieve higher anchoring forces with a probability of 95%. In accordance to this assumption the characteristic value, needed for the design and verification, may be calculated based on the single measurement with the partial factor for scatter according to Equation (6).

5.4 Scatter of impact tests

Due to the scatter of impact tests also the variation of the test results is wide. Because there are lots of parameters affecting the impact tests on road restraint systems, there are numerous reasons for the wide range of test result scatter. The appendix shows a summary of test parameters, which possibly are affecting the results of an impact test TB 81 according to EN 1317-2 [8].

In general, for material properties the scatter (coefficient of variation, v) of many materials is quite well known. However, it is much more difficult to get such information about loadings. For vehicle impact tests, even no knowledge about the scatter is available. Therefore, only rough assessments of the scatter lead to a statement.

Regarding Table 7 in the appendix, it is postulated that the following parameters have an essential influence on the scatter of the test results:

– **Test vehicle** (Tracting vehicle, Trailer without load, Load)

  In general, the scatter concerning the test vehicle is wide. Especially for articulated heavy goods vehicles (HGV) with loads, a wide scatter must be expected. For the different type of vehicles respectively the different impact tests, the following coefficients of variations, v_{tv} may be estimated:

Table 3: Assessment of the coefficient of variation v_{tv} for impact tests concerning the test vehicles

Type of vehicle	Impact test according to EN 1317-2 [9]	Coefficient of variation v_{tv}
Car, Bus	TB 11, TB 21, TB 22, TB 31, TB 32, TB 51	0,15 (15%)
Rigid HGV	TB 41, TB 42, TB 61, TB 71	0,20 (20%)
Articulated HGV	TB 81	0,25 (25%)

– **Test conditions**

The limit deviation of the vehicle mass as well as the location of the center of gravity is defined in EN 1317-1 [8]. The limit deviations of impact speed and angle are defined in EN 1317-2 [9]. According to these limits, the coefficients of variation for the vehicle mass v_{vm}, for the impact speed v_{is} and for the impact angle v_{ia} are expected as follows:

$v_{vm} = 0{,}025 \quad (2{,}5\%)$

$v_{is} = 0{,}015 \quad (1{,}5\%)$

$v_{ia} = 0{,}037 \quad (3{,}7\%)$

According to Equation (2) the coefficient of variation for the test conditions is:

$$v_{tc} = \sqrt{v_{vm}^{2} + v_{is}^{2} + v_{ia}^{2}}$$

$$v_{tc} = \sqrt{0{,}025^2 + 0{,}015^2 + 0{,}037^2} = 0{,}047\ (5\%)$$

– **Test object** (restraint system)

The uncertainties concerning the restraint system are generally higher than these of the test conditions but rather smaller than the scatter according to the test vehicle. For safety barriers with rather complex working mechanism, for instance when it is based on the interaction of different components (e.g. posts and beams), a coefficient of variation v_{to} of 15% may be estimated. For the case of a more simple working mechanism (e.g. for concrete parapets) the coefficient of variation v_{to} may be reduced to 10%.

· Little complex working mechanism:

$v_{to} = 0{,}10 \quad (10\%)$

· More complex working mechanism:

$v_{to} = 0{,}15 \quad (15\%)$

The coefficient of variation v_{IT} describing the scatter of impact tests can be calculated according to Equation (2) as follows. With the calculated coefficient of variation the uncertainties in accordance to the test vehicle, the test condition and the test object will be considered. The results of the calculations are summarized in Table 4.

$$v_{IT} = \sqrt{v_{tv}^{2} + v_{tc}^{2} + v_{to}^{2}}$$

Table 4: Coefficient of variation v_{IT} for the results of impact tests depending on the type of vehicle and the working mechanism of the restraint system

Type of vehicle	Restraint system with little complex working mechanism	Restraint system with more complex working mechanism
Car, Bus	0,19 (19%)	0,22 (22%)
Rigid HGV	0,23 (23%)	0,25 (25%)
Articulated HGV	0,27 (27%)	0,30 (30%)

5.5 Design values of actions

Measurements of anchoring forces and acting momentums recorded during impact tests may be used for the design and verification of the anchorages of road restraint systems on bridge decks. Therefore, the design values of the actions should be calculated based on the measured values N_{IT}, V_{IT} and M_{IT}.

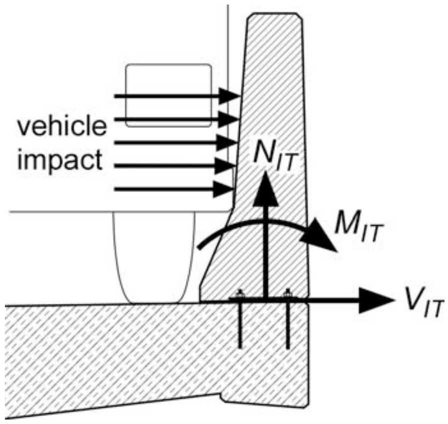


Figure 10: Measurement of anchoring forces N_{IT} and V_{IT} as well as acting momentums M_{IT} during vehicle impact tests

For the design and verification of anchorages of restraint systems on bridge decks the design values N_d, V_d and M_d of the actions have to be calculated as follows:

$$N_d = N_{IT} \cdot \gamma_{IT} \quad (11)$$

$$V_d = V_{IT} \cdot \gamma_{IT} \quad (12)$$

$$M_d = M_{IT} \cdot \gamma_{IT} \quad (13)$$

where:

N_{IT} During impact test measured anchoring tension load

V_{IT} During impact test measured anchoring shear load

M_{IT} During impact test measured anchoring momentum

γ_{IT} Partial factor for impact test results

In general, the design values for accidental actions are equal to the characteristic values. Therefore, the partial factor for impact test results γ_{IT} is corresponding with the partial factor for scatter:

$$\gamma_{IT} = \gamma_s (v_{IT}) \quad (14)$$

where:

$\gamma_s (v_{IT})$ Partial factor for scatter depending on the coefficient of variation for impact test results v_{IT} according to Table 4

The partial factor for scatter γ_s is depending on the coefficient of variation in accordance to Equation (6) respectively Figure 4. The coefficients of variation according to Table 4 lead to the following partial factor for impact test results γ_{IT}.

Table 5: Partial factor for impact test results γ_{IT} for different types of vehicle and different working mechanism of the restraint system

Type of vehicle	Restraint system with little complex working mechanism	Restraint system with more complex working mechanism
Car, Bus	1,9	2,1
Rigid HGV	2,2	2,4
Articulated HGV	2,6	2,9

In accordance to a simplified approach it is proposed, that the following partial factors for impact test results should be used:

– Impact tests with cars or buses
  $\gamma_{IT} = 2{,}0$
– Impact tests with rigid HGV's as well as impact tests with articulated HGV's and restraint systems with simple working mechanism (e.g. concrete parapets)
  $\gamma_{IT} = 2{,}5$
– Impact tests with articulated HGV's and restraint systems with more complex working mechanism (e.g. steel guardrails)
  $\gamma_{IT} = 3{,}0$

6 Anchorage design according to the attachment capacity

6.1 General

Anchored respectively rigidly on the bridge deck fixed deformable safety barriers (e.g. steel guardrails) transfer loadings into the edge beam of the bridge in case of a vehicle impact. These forces and momentums are limited by the capacity of the attachment. Therefore, the anchorage design may be executed in accordance to the attachment capacity.

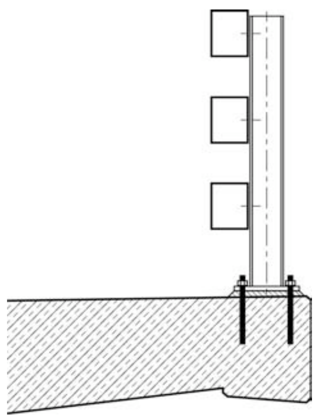


Figure 11: Deformable safety barrier, e.g. steel guardrail, which is rigidly anchored on the edge beam of the bridge

6.2 Scatter of attachment capacity

According to the presented principles of capacity design (Section 2.3) the design actions are depending on the bearing capacity of the attachment. The bearing capacity may be calculated according to design standards as well as measured by a single loading test. Both procedures include uncertainties, which shall be described by the scatter of the attachment capacity.

Determine the attachment capacity with more than one loading test leads to more information about the distribution of the attachment resistance. In such cases the representative value (e.g. the 95%-fractile) should be determined in accordance to the classical statistical theory, which is discussed in Section 5.2. Generally, the greater the number of tests the larger the information about the distribution and therefore the more precise the determination of the characteristic values of the resistance.

For calculations according to standards as well as in the case of single tests, the scatter of the resistance shall be considered as follows. In Reference [13] coefficients of variation for different parameters and failure modes are given.

– **Beam in bending**

For attachments consisting of rolled steel beams (e.g. guardrail posts) in [13] the following coefficients of variation are given [13]:

· The coefficient of variation for the dimensional deviations of rolled steel sections (area of the cross section, section modulus, moment of inertia) is given as:

$v_{dd} = 0{,}04 \quad (4\%)$

· The coefficient of variation for the model-factors for ultimate loads of beams and deflection of beams is given as:

$v_{mf} = 0{,}07 \quad (7\%)$

· The coefficient of variation for the material properties of structural steel concerning the yield stress or the ultimate stress of steel is given as:

$v_{mp} = 0{,}08 \quad (8\%)$

According to Equation (2) the coefficient of variation for the capacity of a beam in bending is as follows:

$$v_{AC} = \sqrt{v_{dd}^{\ 2} + v_{mf}^{\ 2} + v_{mp}^{\ 2}}$$

$$v_{AC} = \sqrt{0{,}04^2 + 0{,}07^2 + 0{,}08^2} = 0{,}11\left(11\%\right)$$

– **Welded joint**

If the resistance values of attachments are defined by welded joints (e.g. posts with welded baseplates), the coefficient of variation for the attachment capacity is normally large, because of the wide scatter of welding. In accordance to [13] the coefficient of variation for failures of welded joints v_{wf} can be 20%. The coefficient of variation for the attachment capacity is for this reason estimated the same:

$v_{AC} = v_{wf} = 0{,}20 \quad (20\%)$

6.3 Design values of actions

The design values of actions used for the verification according to the attachment capacity are based on the calculated characteristic values $N_{k,AC}$, $V_{k,AC}$ and $M_{k,AC}$ of the attachment resistance or values of anchoring forces and momentums measured with a single loading test.

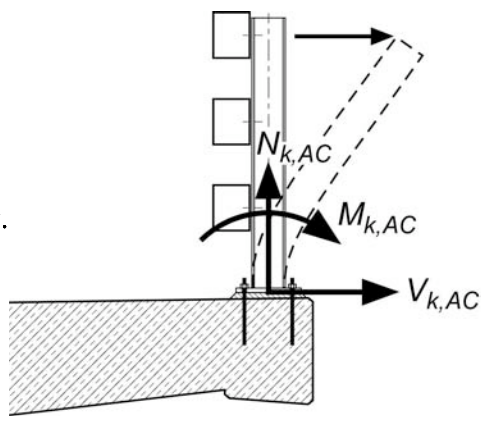


Figure 12: Calculated or with an single loading test measured characteristic resistance values $N_{k,AC}$, $V_{k;AC}$ and $M_{k,AC}$ of the attachment

For the design and verification of anchorages of restraint systems on bridge decks the design values N_d, V_d and M_d of the actions should be calculated as follows:

$$N_d = N_{k,AC} \cdot \gamma_{AC} \quad (15)$$

$$V_d = V_{k,AC} \cdot \gamma_{AC} \quad (16)$$

$$M_d = M_{k,AC} \cdot \gamma_{AC} \quad (17)$$

where:

$N_{k,AC}$ Calculated characteristic tension load of the attachment respectively tension load according to a single loading test

$V_{k,AC}$ Calculated characteristic shear load of the attachment respectively shear load according to a single loading test

$M_{,kAC}$ Calculated characteristic momentum of the attachment respectively momentum according to a single loading test

γ_{AC} Partial factor for attachment capacity

In general, the design values for accidental actions are equal to the representative values. Therefore, the partial factor for attachment capacity γ_{AC} is corresponding with the partial factor for scatter:

$$\gamma_{AC} = \gamma_s (v_{AC}) \quad (18)$$

where:

$\gamma_s (v_{AC})$ Partial factor for scatter depending on the coefficient of variation for the attachment capacity

The partial factor for scatter γ_s is depending on the coefficient of variation according to Equation (6) respectively Figure 4. With the coefficients of variation v_{AC} specified above, the partial factor for attachment capacity γ_{AC} will be as follows:

- Bending failure of beams
  $\gamma_{AC} = 1{,}4$
- Failure of welded joints
  $\gamma_{AC} = 2{,}0$

7 Anchorage design according to the breakaway capacity

7.1 General

Deformable safety barriers which are not anchored on the bridge deck or only fixed with rupture joints (e.g. connected prefabricated concrete wall elements) can transfer only relative small loads into the edge beam of the bridge in the case of a vehicle impact. If the restraint system is not fixed at all, only friction forces are acting. In the case of rupture joints, the maximal acting load is given by the breakaway capacity.

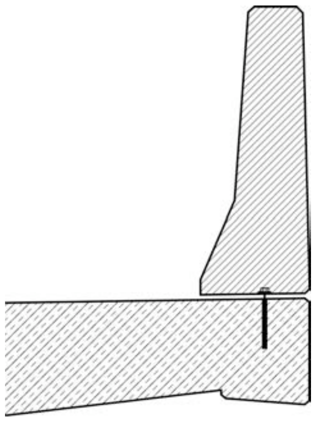


Figure 13: Deformable safety barrier, e.g. connected prefabricated concrete wall elements, fixed on the edge beam of the bridge with rupture joints

7.2 Scatter of breakaway capacity

Due to the desired breakaway function, the scatter of the breakaway capacity of rupture joints has to be small. For this reason breakaway constructions often are based on the rupture of bolts. However, in [13] the coefficient of variation for bolt failure v_{bf} is given as follows. It is assumed, that the coefficient of variation for the breakaway capacity v_{BC} will be equal.

$$v_{BC} = v_{bf} = 0{,}05 \ldots 0{,}06 \ (5 \ldots 6\%)$$

If a breakaway construction is based on other failure mechanism than bolt failure, e.g. the failure of a flange or even the failure of a welding joint, the coefficient of variation is larger in accordance with this failure mode.

7.3 Design values of actions

If the breakaway capacity of rupture joints is used for the design and verification of the anchorages, the design values of the actions may be determined with the calculated characteristic values of the breakaway resistance $N_{k,BC}$, $V_{k,BC}$ and $M_{k,BC}$.

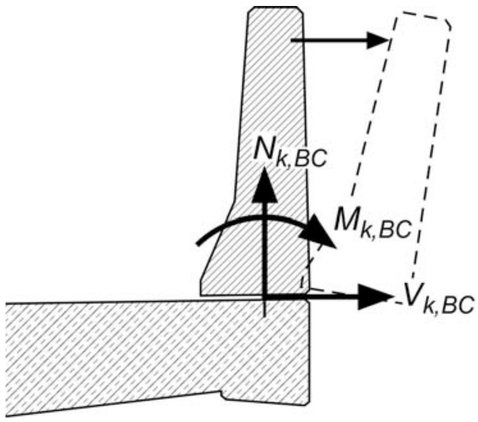


Figure 14: Calculated characteristic values of the resistance of the rupture joint $N_{k,BC}$, $V_{k,BC}$ and $M_{k,BC}$

For the design and verification of anchorages of rupture joints the design values N_d, V_d and M_d of the actions should be calculated as follows:

$$N_d = N_{k,BC} \cdot \gamma_{BC} \quad (19)$$

$$V_d = V_{k,BC} \cdot \gamma_{BC} \quad (20)$$

$$M_d = M_{k,BC} \cdot \gamma_{BC} \quad (21)$$

where:

$N_{k,BC}$ Calculated characteristic resistance of breakaway tension load

$V_{k,BC}$ Calculated characteristic resistance of breakaway shear load

$M_{k,BC}$ Calculated characteristic resistance of breakaway momentum

γ_{BC} Partial factor for breakaway capacity

In general, the design values for accidental actions are equal to the representative actions. Therefore, the partial factor for breakaway capacity γ_{BC} is corresponding with the partial factor for scatter:

$$\gamma_{BC} = \gamma_s (v_{BC}) \quad (22)$$

where:

$\gamma_s (v_{BC})$ Partial factor for scatter depending on the coefficient of variation for breakaway capacity

The partial factor for scatter γ_s is depending on the coefficient of variation according to Equation (6) respectively Figure 4. With the coefficient of variation v_{BC} specified in Section 7.2 above, the partial factor for the attachment capacity will be γ_{BC} = 1,18 ... 1,22. It is recommended to set the partial factor as follows:

$$\gamma_{BC} = 1{,}2$$

8 Summary

Table 6 is summarizing the partial factors needed for the design and verification of anchorages of restraint systems on bridge decks. The factors are depending on the safety barrier and its anchorage respectively the appropriate design method. However, the partial factors are depending on the scatter of the resistance of the anchorage respectively the scatter of the action in the case of verifications with impact tests.

The partial factor is varying in a wide range between γ_{BC} = 1,2 for the design of anchorages of rupture joints with a small scatter and γ_{IT} = 3,0 for the design of anchorages of restraint systems in accordance to impact test results with a wide scatter.

Table 6: Partial factors for design and verification of anchorages of restraint systems on bridge decks

	Connection / anchorage of the road restraint system on the bridge deck		
	Restraint system is monolithic jointed (reinforced concrete structure)	Restraint system is anchored respectively rigidly fixed	Restraint system is not anchored or only fixed with rupture joint (breakaway)
Rigid safety barriers	Structural design according to **European/National codes** $F_{d,y}$ **= 100 kN** according to ENV 1991-2-7: 1998 [2] γ_M **= 1,3** according to material properties of concrete	Anchorage design according to **impact testing** γ_{IT} **= 2,0 ... 3,0** according to the test vehicle and the working mechanism of the restraint system: γ_{IT} = 2,0 cars, buses γ_{IT} = 2,5 rigid HGV or articulated HGV and simple working mechanism γ_{IT} = 3,0 articulated HGV as well as complex working mechanism	not common
Deformable safety barriers	not possible	Anchorage design according to the **attachment capacity** γ_{AC} **= 1,4 ... 2,0** according to the failure mode of the attachment: γ_{AC} = 1,4 bending failure of steel beams (e.g. guardrail posts) γ_{AC} = 2,0 failure of welded joints (e.g. between posts and bases)	Anchorage design according to the **breakaway capacity** γ_{BC} **= 1,2** according to the breakaway construction: γ_{BC} = 1,2 ruptur joints based on bolt failure

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Appendix

Table 7: Parameters with effect on the results of impact tests with Articulated HGV (TB 81 according to EN 1317-2) in accordance to [11]

Parameter
Tracting vehicle – total vehicle mass – height of centre of gravity over ground, without trailer – position of centre of gravity in x-direction, without trailer – height of centre of gravity over ground, with trailer – position of centre of gravity in x-direction, with trailer – resistance of vehicle front – dimensions of wheels – dimensions of tyres – friction factor of tyres – position of wheels between impact and rebound – vertical load on tracting vehicle – distance of axles – total length – resistance of vehicle rear – path of suspension until stop – resistance of suspension
Trailer without load – analogous to parameters of tracting vehicle
Load – mass – height of centre of gravity over ground – position of centre of gravity in x-direction – shift-path in x-direction – shift-path in y-direction – friction factor of loading area and load
Test area – grip of ground surface – humidity – incline – evenness – transition to ground under restraint system
Test conditions – impact velocity – impact angle – total mass

Parameters
Test object (restraint system) – fixing of posts – cross-section and momentum of resistance of posts – material of posts – welding seam between post and sheet – distance between posts – resistance of fixing between post and beam – position of posts referring to the point of impact – height of beams over ground – cross-section and momentum of resistance of beams – length of shifting in connections of beams – pre-tension of beams – shifting of terminal fixing