0. Introduction: Dynamic Loads and Applications

Introduction

Introduction

Common engineering design usually focuses around static loads. With this in mind, is important to realise that static loads are indeed a very special case that - theoretically speaking - almost never occurs in real life.

Clearly, the applicable safety factors for static design account for most usual effects of minor dynamic loading situations that are commonly addressed by using a static simplification.

This brochure is intended to point out those cases, however, where such static simplification may cause severe misjudgement and usually under-design of important structures.

The following sections seek to raise the awareness towards dynamic design problems, show how to classify, model and calculate them, and finally suggest an appropriate Hilti solution.

Typical Dynamic Actions

As will be described in detail in the following section, dynamic actions can generally be classified into 3 different groups:

- Fatigue loads
- Seismic loads
- Shock loads

Although the exact technical definitions will be given in the following section, a simple indicative explanation of each is helpful at this stage.

- Fatigue loads are such that recur frequently during the life of a structure and are generally expected loads.
- Seismic loads are induced by deformations of a structure due to seismic activity that may or may not be considered an ultimate state for the structure.
- Shock loads are typically unique actions that can in some cases recur during the life of the structure.

The following sections describe typical applications where dynamic actions occur, and where static simplification would generally lead to significant under-design.

Examples for Fatigue Loads

Two main groups of fatigue type loading can be identified:

- **Vibration type loading** of fasteners with very high recurrence and usually low amplitude.
- **Repeated loading and unloading** of structures with high loads and frequent recurrence.

Vibration type loading is generally encountered in structures, such as

- **Ventilators** (most relevant standards and regulations assume a standard eccentricity to design for!)
- Various **production machinery** (rotating and linear)
- **Breakers** for rock, gravel an alike (rotating and linear)
- **Structures subject to unsteady hydraulic effects** (power plant equipment, pipe fasteners with frequent water hammer action, structures subject to water vortex loads, etc.)
- **Fastenings subject to indirect loading** through vibrating equipment in nearby location.

Usually, these cases are properly identified as "dynamic" and correspondingly designed for. Situations of "repeated loading and unloading" (e.g. vibrations) are much less spectacular and much less obvious as to their dynamic relevance. Thus, it is an explicit objective of this brochure to raise the awareness of the designing engineer especially with respect to such applications. Due to the substantial loads they usually include, fasteners are very frequently stressed close to their limits which in turn may well cause failure.

Typical examples are:

- **Cranes** (tower cranes, workshop cranes, crane rails, etc.)
- **Elevators** (guide rails, load carrying equipment, etc.)
- **Hoisting equipment** (autohoists, fastenings of jacks, etc.)
- **Robots** and other turning load carrying equipment
- **Bridge components**
- **Loading structures** (shutes for bulk material, conveying systems, etc.)

Examples for Seismic Loads

Generally, all fastenings in structures situated in seismically active areas can be subject to seismic loading. However, due to cost considerations, usually only critical fastenings whose failure would result in loss of human life or significant weakening of the overall structure are designed for seismic loads. Furthermore, structures with importance for the time after an earthquake are generally equipped with such fastenings.

Usual examples are:

- All fastenings of the **primary structural members** in buildings within active earthquake zones
- **Fastenings of machinery and equipment mounted overhead and on walls** (air conditioning aggregates, ventilators, heavy ducts and pipes, etc.)
- **All fastenings in hospitals, schools** and other structures that are generally used as shelters after catastrophic events
- **Fastenings of critical equipment** and corresponding sub-structure (major gas lines, equipment in the chemical and petrochemical industry, nuclear equipment, etc.)

Examples of Shock Loading

Shock loads are mostly unusual loading situations, even though sometimes they are the only loading case a structure is designed for (e.g. crash barriers, protection nets, etc.) Most generally, shock loads occur as the result of

- **Explosions** (e.g. in industrial plants, power stations, war action, etc.)
- **Falling parts** and structures (e.g. as a result of seismic action, failure of structures, expected failure of wearable parts as is the case with rubber noise insulators for machinery, etc.)
- **Extraordinary traffic loads** (crash barriers, etc.)
- **Hydraulic loads** (e.g. water hammers, extraordinary operating conditions in hydro structures)

It should be emphasised, that **shock loads** are far more **frequent** than usually assumed. Furthermore, the **load increases can be dramatic** and easily in the order of 100 times the static load (see later examples).

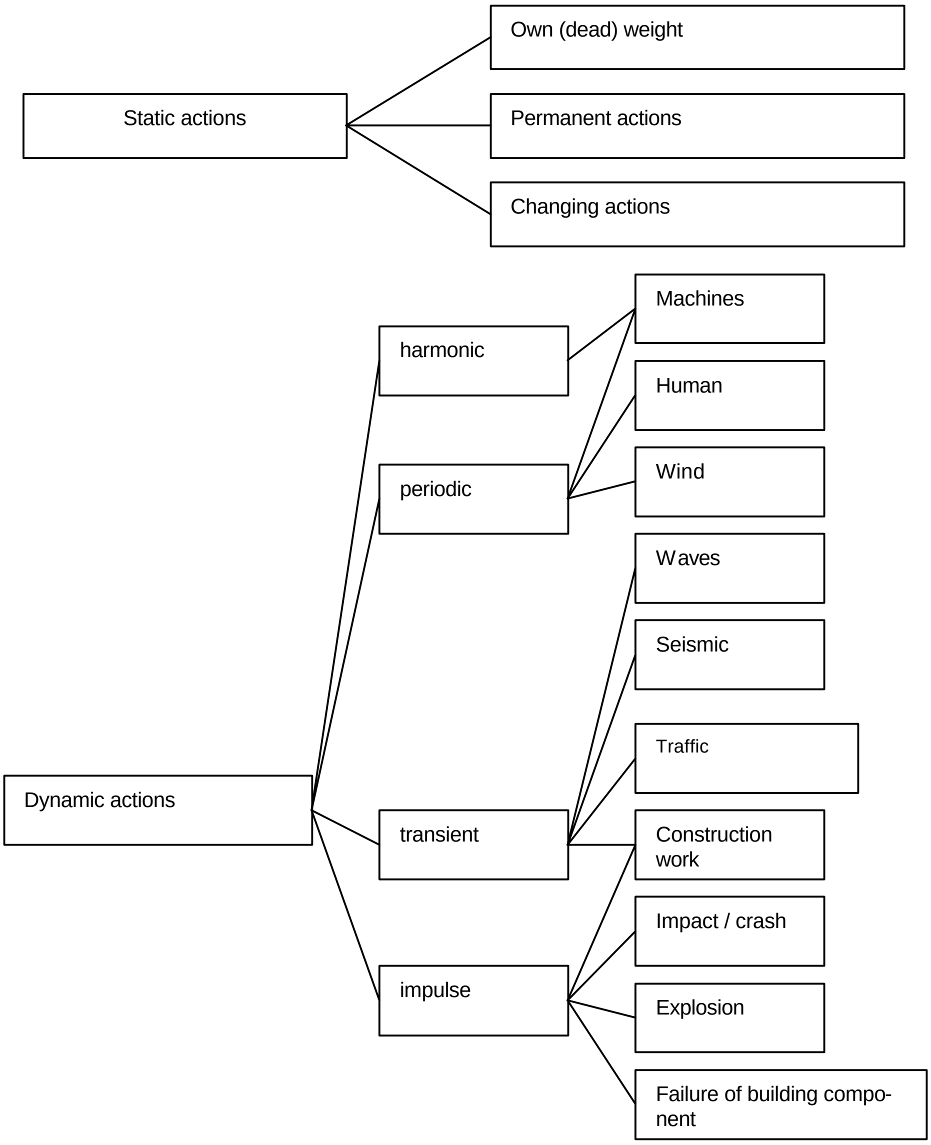
For example, a part posed directly onto an undeflected beam and then released instantly will cause the acting forces to double compared to the usually assumed static loading with infinitely slow loading (which is seldom the case).

1. Impact on Fasteners

Actions (loads)

Review of actions

Often, it is not possible to accurately determine the actions (loads) to which anchor / fasteners are subjected. In this case, it is possible to make it with estimates for which standards specify the minimum levels to be used for most modes of loading. The uncertainty in determining a action (load) is compensated by selecting suitably adapted safety factors.



Impact on Fasteners

Static loads

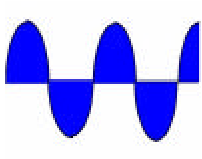
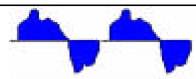
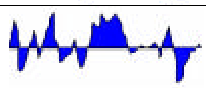
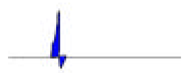
Static loads can be segregated as follows:

- Own (dead) weight
- Permanent actions
  Loads of non-loadbearing components, e.g. floor covering, screed, or from constraint (due to temperature change or sinking of supports / columns)
- Changing actions
  working loads (fitting / furnishing , machines, "normal" wear)
  Snow
  Wind
  Temperature

Dynamic actions

The main difference between static and dynamic loads is the effectiveness of inertia and damping forces. These forces result from induced acceleration and must be taken into account when determining section forces and anchoring forces.

Classification	Fatigue	Fatigue under few load cycles	Impact,impulse-like load
Frequency of occurrence, number of load cycles	$10^4 < n \geq 10^8$	$10^1 < n < 10^4$	$1 < n < 20$
Rate of strain	$10^{-6} < \varepsilon' > 10^{-3}$	$10^{-5} < \varepsilon' > 10^{-2}$	$10^{-3} < \varepsilon' > 10^{-1}$
Examples	Traffic loads, machines, wind, waves	Earthquakes / seismic, man-made earthquakes	Impact, explosion, sudden building component failure
	Fatigue	**Seismic**	**Shock**

Action	**Chronological sequence**		**Possible cause**
harmonic (alternating load)		sinusoidal	Out of balance rotating machines
harmonic (compressive / tensile pulsating load)		sinusoidal	
periodic		random, periodic	Regularly impacting parts (punching machines)
stochastic		random, non periodic	Earthquakes / seismic, rail and road traffic
Impact / shock		random, of short duration	Impact / crash, explosion, rapidly closing valves

Actions relevant to fatigue

Actions causing fatigue have a large number of load cycles which produce changes in stress in the affected fastening. These stresses result in a decrease in strength which is all the greater the larger the change in stress and the larger the number of load cycles are (fatigue). When evaluating actions causing fatigue, not only the type of action, but also the planned or anticipated fastening life expectancy is of major importance.

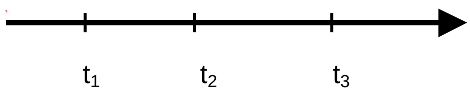
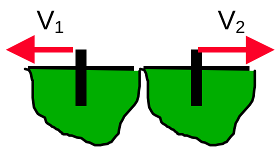
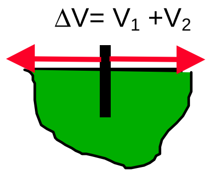
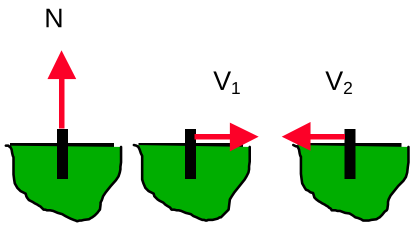
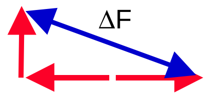
Direct / indirect action

A direct action on a fastening exists when the fastening is immediately stressed by forces, e.g. due to a machine in operation. A machine in operation sets up vibration in its vicinity, also through its supports, which then indirectly incites building component vibration. This can lead to fatigue stressing of fastenings.

Determination of actions causing fatigue

In most cases, the magnitude of action causing fatigue cannot be determined accurately. The chronological sequence of the action and the influence on each other of building component, fastened part and fastener are crucial factors that have to be stipulated by the design engineer. When determining the fatigue-relevant magnitude of an action to which a fastener is subjected, it is important, however, to remember that also the actions not occurring at the same time summate.

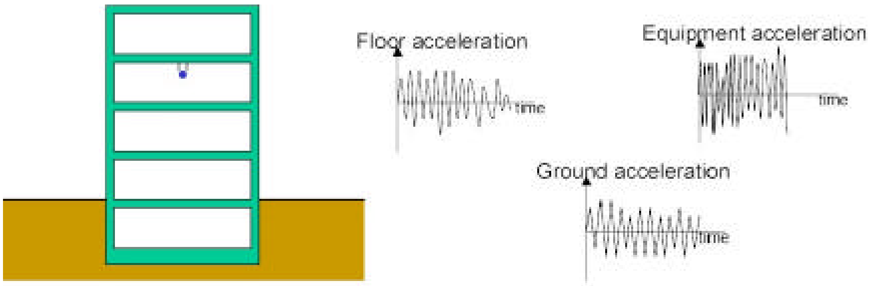
From a design / static point of view, the actions occurring at different times are regarded separately. In the case of fatigue-relevant loading, all applicable loads must be determined over the anticipated fastening life expectancy. The following chart is intended to illustrate this:

Static design	Dynamic design
time axis   The design force is either V1 or V2.	 The dynamic design force is ΔV.
 The design force is either N, V_1 or V_2.	 The dynamic design force is $\Delta F = \sqrt{N^2 + (V_1 + V_2)^2}$

Impact on Fasteners

Earthquakes / seismic actions

Ground movement during an earthquake / seismic tremors leads to relative displacement of a building foundation. Owing to the inertia of its mass, the building cannot or is unable to follow this movement without deformation. Due to the stiffness of the structure, restoring forces are set up and vibration is induced. This results in stress and strain for the structure, the parts fastened and the installations. Earthquake frequencies often lead to resonance phenomena which cause larger vibration amplitudes on the upper floors. The fastened components, the installations and the fasteners or anchors required for them are then heavily stressed.



In view of the low ductility of anchors / fasteners, seismic loads generally have to be taken up by a high loading capacity and very little deformation. A fastening should be able to withstand design basis earthquakes without damage. Determining the forces acting on a fastening is difficult and specialists thus provide them.

Shock

Shock-like phenomena, i.e. a crashing vehicle, ship or aeroplane and falling rocks, avalanches and explosions, have such characteristics as a very short duration and tremendously high forces which, however, generally only occur as individual peaks. As the probability is slight that such a phenomenon will occur during the life expectancy of the building components concerned, plastic deformation is usually permitted if such an event takes place in order to avoid an uneconomical design. This means that the behaviour of the fastening must be as ductile as possible and that it will be replaced after the phenomenon has occurred.

Under a loading of very brief duration, fastenings also display better behaviour in the elastic range which permits higher permissible shock loads. These are determined during suitable tests, e.g. according to ACLS9818.

The engineer responsible for a specific project must work out the magnitude of the action and the permissible deformation (elastic, elastic-plastic) each time.

Extraordinary actions

Extraordinary actions include, among others, fire and corrosion. The implications for fastenings are described in other brochures.

Behaviour of materials

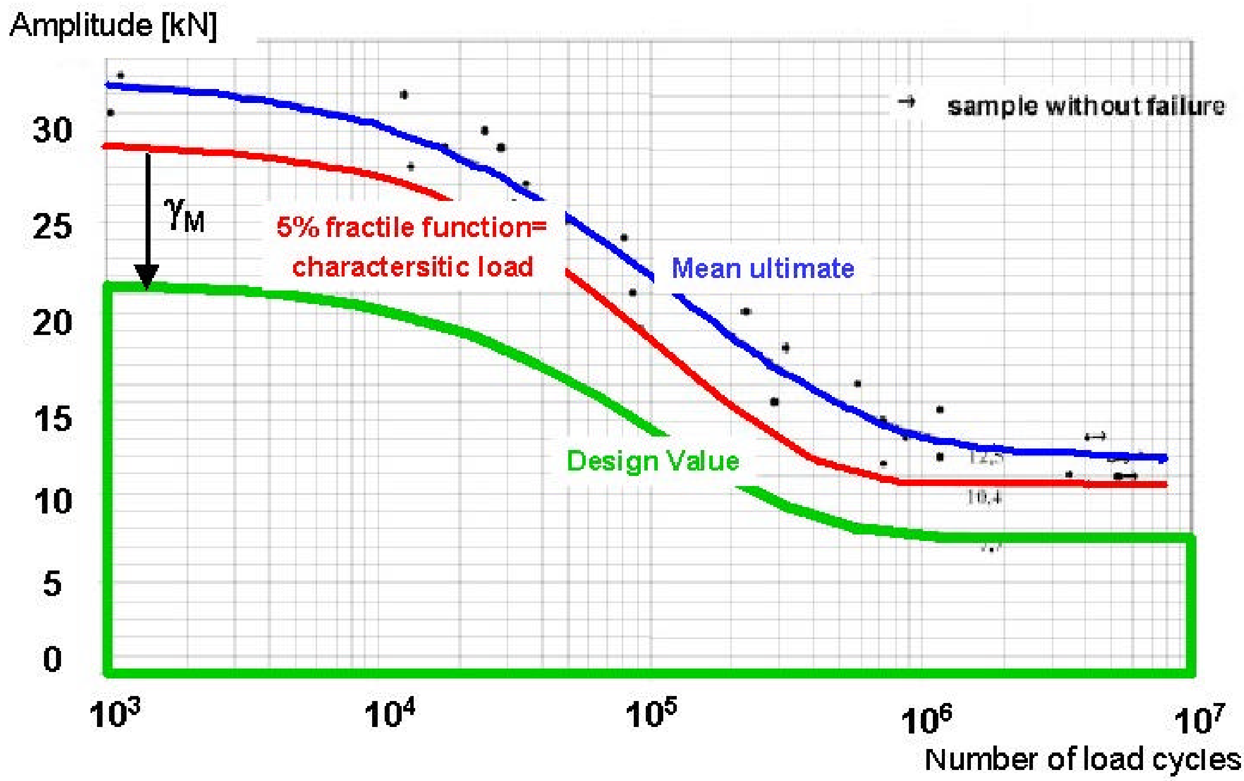
Material behaviour under static loading

The behaviour of material under static loading is described essentially by the strength (tensile and compressive) and the elastic-plastic behaviour of the material, e.g. modulus of elasticity, shear (lateral) strain under load, etc. These properties are generally determined by carrying out simple tests with specimens.

Fatigue behaviour

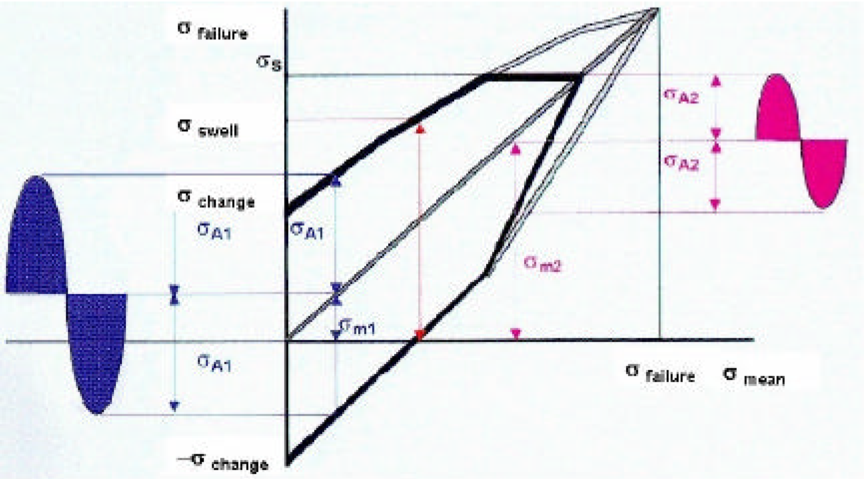
If a material is subjected to a sustained load that changes with respect to time, it can fail after a certain number of load cycles even though the upper limit of the load withstood up to this time is clearly lower than the ultimate tensile strength under static loading. This loss of strength is referred to as material fatigue.

It is widespread practice to depict the fatigue behaviour of a material in the form of so-called S-N curves (also called Wöhler curves). They show the maximum load amplitude that can be withstood at a given number of load cycles (for action with a sinusoidal pattern). If a level of stress can be determined at which failure no longer occurs after any number of load cycles, reference is made to fatigue strength or short-term fatigue strength. Higher loads that can often only be withstood for a limited time, come within the low-cycle fatigue range or range of fatigue strength for finite life.



Fatigue behaviour of steel

The fatigue behaviour of various grades of steel is determined during fatigue (Wöhler) tests. If a series of fatigue tests is carried out using different mean stresses, many fatigue curves are obtained from which a decrease in the fatigue-resisting stress amplitude, σ_A , can be identified. The graphical depiction of the relationship between the mean stress, σ_m , and the fatigue-resisting stress amplitude, σ_A , in each case is called the stress-number (S-N) diagram. Smith's representation is mostly used today.



The grade of steel has a considerable influence on the alternating strength. In the case of structural and heat-treatable steels, it is approx. 40% of the static strength, but this, of course, is considerably reduced if there are any stress raisers (notch effects). The fatigue strength of actual building components is influenced by many factors:

- Stress raiser (notch effect)
- Type of loading (tensile, shear, bending)
- Dimensions
- Mean stress

Stainless steels as well as plastics do not have a pronounced fatigue durability (endurance) so that fatigue failure can even occur after load cycles of $>10^7$.

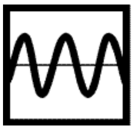
Fatigue behaviour of concrete

The failure phenomenon of concrete under fatigue loading is the same as under static loading. In the non-loaded state, concrete already has micro-cracks in the zone of contact of the aggregates and the cement paste which are attributable to the aggregates hindering shrinkage of the cement paste. The fatigue strength of concrete is directly dependent on the grade of concrete. A concrete with a higher compressive strength also has a higher fatigue strength. Concrete strength is reduced to about 60 – 65% of the initial strength after 2'000'000 load cycles.

2. Anchor Behaviour

Behaviour when subjected to dynamic action

In view of the fact that dynamic action can have very many different forms, only the basic information has been given in the following that is required to understand fastening behaviour.



Fatigue

Fatigue behaviour of single anchor in concrete

The fatigue behaviour of steel and concrete is described in chapter 1. When a large number of load cycles is involved, i.e. $n>10^4$, it is always the anchor in single fastenings that is crucial (due to steel failure). The concrete can only fail when an anchor is at a reduced anchorage depth and subjected to tensile loading or an anchor is at a reduced distance from an edge and exposed to shear loading.

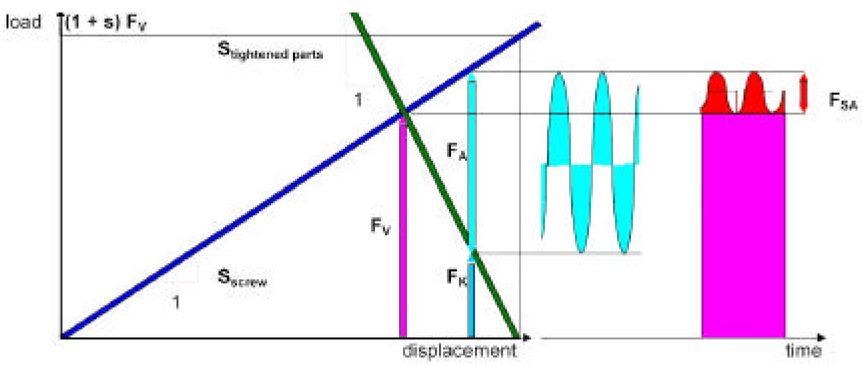
In the range of short-term strength, i.e. $n<10^4$, the concrete can also be crucial. This is dependent very much on the cross-sectional area of the steel in relation to the anchorage depth, i.e. a large diameter combined with a small anchorage depth => concrete failure or a small diameter with a large anchorage depth => steel failure.

Multiple-anchor fastenings

Individual anchors in a multiple-anchor fastening can have a different elastic stiffness and a displacement (slip) behaviour that differs from one anchor to another, e.g. if an anchor is set in a crack. This leads to a re-distribution of the forces in the anchors during the appearance of the load cycles. Stiffer anchors are subjected to higher loads, whereas the loads in the weaker anchors is reduced. Allowance is made for these two effects by using a reduction factor for multiple-anchor fastenings. It is determined during defined tests.

Influence of anchor pretensioning

The behaviour of anchors under dynamic loading is decisively improved by anchor pretensioning (preload). If an external working load, F_A, acts on a pretensioned anchor fastening, the fatigue-relevant share of the load cycle taken by the bolt is only the considerably smaller share of the force in the bolt, F_{SA}.



F_A: external working load
F_K: clamping force
F_{SA}: share relevant to fatigue

F_V: pretensioning force
S_{screw}: bolt stiffness
$S_{\text{clamped parts}}$ stiffness of clamped parts

Consequently, the existence of a pretensioning force is of crucial significance for the fatigue behaviour of an anchor (fastener). In the course of time, however, all anchors lose some of the pretensioning force. This loss is caused by creep of the concrete, primarily in the zone in which the load is transferred to the concrete, due to relative deformation in turns of the bolt thread and relaxation in the bolt shank.

Tests have shown that comparable losses of pretensioning force can be measured in anchors (fasteners) that have quite different anchoring mechanisms, such as cast-in headed studs, undercut anchors and expansion anchors. As a result, a residual pretensioning force of 30 to 50% the initial force must be expected after a considerable time if no countermeasures are taken.

Pretensioning force of anchor in a crack

If an anchor is set in a crack, the pretensioning force decreases to zero and cannot, consequently, be taken into account for a fastening being designed to withstand fatigue.

Influence of pretensioning on anchors loaded in shear

The clamping force between the part fastened and the base material, as shown above, is directly dependent on the pretensioning force in the anchor. As a rule, the fatigue strength of steel under shear loading is not as high as under pure tensile loading. In view of this, an attempt should be made to transfer at least a part of the dynamic shear force into the concrete by friction. Accordingly, if the pretensioning force is high, the share that the anchor must take up is smaller. This has a considerable influence on the number and size of anchors required.

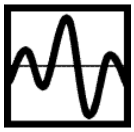
It is recommended that shear pins be provided to take up the dynamic shear forces. As a result, the anchors, provided that the through-hole has a suitable shape, can be designed for pure tensile loading.

Pretensioning force in stand-off fastenings

In stand-off fastenings, the section of the bolt above the concrete is not pretensioned. The type of threaded rod alone, i.e. rolled after heat treatment or tempered after heat treatment, thus determines the fatigue durability of the fastenings. The pretensioning force in anchors is, nevertheless, important to achieve a high level of fastening stiffness.

Influence of type of thread

How the thread is produced, has a decisive influence on the fatigue strength. A thread rolled after bolt heat treatment has a higher ultimate strength than a thread tempered after heat treatment. All threads of Hilti anchors are rolled after heat treatment. Similarly, the diameter of a thread has a decisive influence on the ultimate strength. This decreases with increasing diameter.



Earthquakes (seismic loading)

Load peaks caused by earthquakes

Anchors (fasteners) subjected to seismic loading can, under circumstances, be stressed far beyond their static loading capacity.

In view of this, the respective suitability tests are carried out using a level of action (loading) that is considerably higher than the working load level. The behaviour of anchors under seismic action depends on the magnitude of loading, the direction of loading, the base material and the type of anchor. After an earthquake, the loading capacity (ultimate state) of an anchor is considerably reduced (to 30 – 80% of the original resistance.)

Anchor design as a part of the overall concept

When designing anchor fastenings, it is important to remember that they cannot be regarded as something isolated to take up seismic forces, but that they must be incorporated in the overall context of a design. As anchors are generally relatively short and thus also stiff items, the possibility of taking up energy in an anchor (fastener) is restricted. Other building components are usually more suitable for this purpose. It is also difficult to foresee what loads will actually be imposed.

Impact and shock-like loads

Load increase times in the range of milliseconds can be simulated during tests on servo-hydraulic testing equipment. The following main effects can then be observed:

- deformation is greater when the breaking load is reached.
- the energy absorbed by an anchor is also much higher.
- breaking loads are of roughly the same magnitude during static loading and shock-loading tests.

In this respect, more recent investigations show that the base material (cracked or non-cracked concrete), has no direct effect on the loadbearing behaviour.

Suitability of anchors for dynamic loading

Suitability under fatigue loading

Both mechanical and chemical anchors are basically suitable for fastenings subjected to fatigue loading. As, first and foremost, the grade of steel is crucial, Hilti manufactures the HDA and HVZ anchors of special grades of steel resistant to fatigue and has also subjected them to suitably tests. Where other anchors are concerned, global statements about ultimate strengths have to be relied on, e.g. those from mechanical engineering.

Suitability under seismic loading

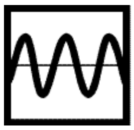
Where fastenings subjected to seismic loading are concerned, chemical anchors take preference. There are, however, accompanying requirements to be met, such as behaviour in a fire or at high temperatures, i.e. load-displacement behaviour, which restrict the use of this type of anchor and make mechanical systems preferable.

Suitability under shock loading

To date, mechanical anchor systems have been used primarily for applications in civil defence installations. These mechanical anchors have had their suitability proofed when set in cracked concrete. Recently, adhesive systems suitable for use in cracked concrete have been developed, e.g. the HVZ anchor, whose suitability for shock loading is also verified. For other shock-like loads, such as those acting on the fastenings of guide rail systems, both mechanical anchors, e.g. fastening of New Jersey profiles with the HUC anchor, and chemical systems, e.g. the HAS with the HVU for crash barrier systems, can be considered.

3. Anchor Design

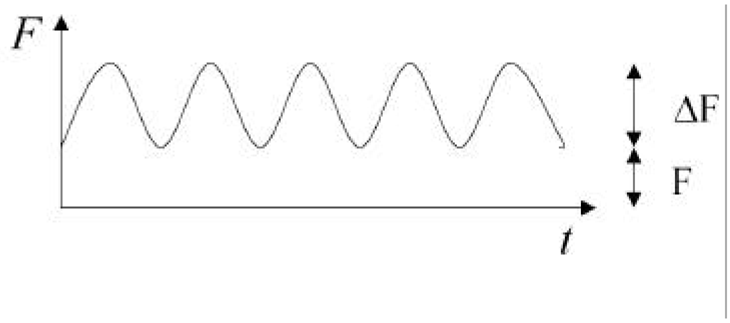
The resistance of anchors for the different dynamic impacts varies significantly. On the following pages the state of the art is briefly described. In addition to this the national and international regulations have to be considered.



Fatigue

External load

The fatigue loads are described often as repeated changes between a minimum and a maximum load level. The smallest, continuously acting load is the static load F; the difference between the continuously acting load F and the maximum load is the fatigue-relevant part of the load ΔF. For shear loads the fatigue-relevant load ΔV acts directly on the fastener if the friction between baseplate and base material is exceeded. For tensile loads the fatigue relevant part of the external load ΔN in the bolt has to be determined.



For a simplified design according to the DIBt-approval all loads are assumed to be fatigue relevant (ΔF=F+ΔF), friction and the pretension force in the anchor are not considered (=0).

Prestressing force in the anchor

The prestressing force in uncracked concrete, that can be taken into account respecting all the long term effects, is:

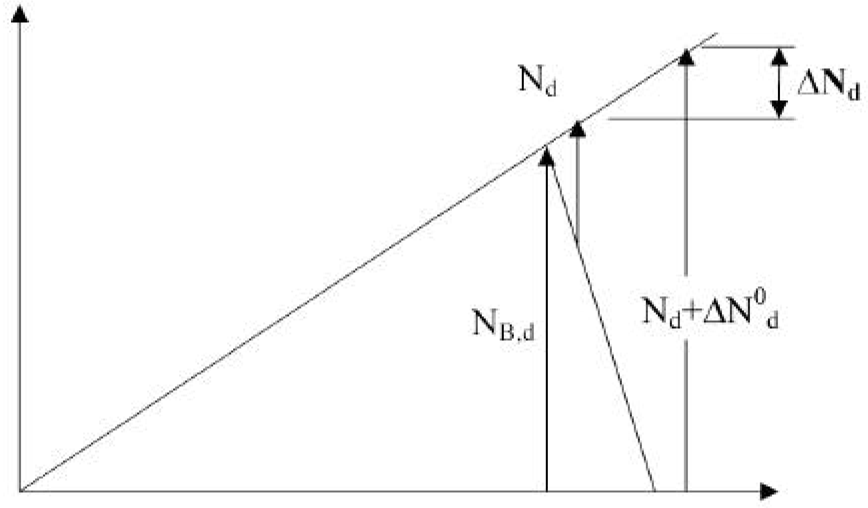
$$F_{B,d} = \frac{k_1 \cdot M_d \cdot k_\infty}{k_u \cdot d}$$

with

$F_{B,d}$	pretension force in the anchor
k_1	factor determined in tests = 0.5
M_d	tightening torque [Nm]
k	long term factor without poststressing 0.3 for HDA and 0.2 for HVZ with regular poststressing: 0.4 for HDA and 0.3 for HVZ
k_u	conversion factor = 0.3
d	nominal anchor diameter [mm]

In a crack the pretension force vanishes and is therefor equal to 0.

Fatigue relevant part of the tensile force in the anchor



Force in bolt:

at static Load N_d:

$$if\ N_d \le F_{B,d} \cdot (1+s) : N_{u,d} = N_d$$

$$if\ N_d > F_{B,d} \cdot (1+s) : N_{u,d} = N_d \cdot \frac{s}{1+s}$$

at maximum load $N_d + \Delta N^0_d$:

$$if\ N_d + \Delta N^0_d \le F_{B,d} \cdot (1+s) : N_{o,d} = \left(N_d + \Delta N^0_d\right)\frac{s}{1+s}$$

$$if\ N_d + \Delta N^0_d > F_{B,d} \cdot (1+s) : N_{o,d} = \left(N_d + \Delta N^0_d\right)$$

s = 0.67

fatigue-relevant tensile force in bolt: $\Delta N_d = N_{o,d} - N_{u,d}$
minimum clamping force: $N_{k,min} = (N_d + \Delta N^o_d) - N_{o,d}$

Fatigue relevant part of the shear force in the anchor

The friction resistance is: $V_{Rd} = N_{k,min} * \mu$

$N_{k,min}$	minimum clamping force
μ	friction coefficient = 0.2

If maximal shear force $V_d + \Delta V^o_d \le V_{Rd}$, then the acting force on the anchor $\Delta V_d = 0$, otherwise the total external force is assumed to act on the anchor $\Delta V_d = \Delta V^o_d$.

Static design

The static design should be done according to normal anchor design in accordance with national and international regulations and approvals (ETA, ICBO, etc).

Fatigue design

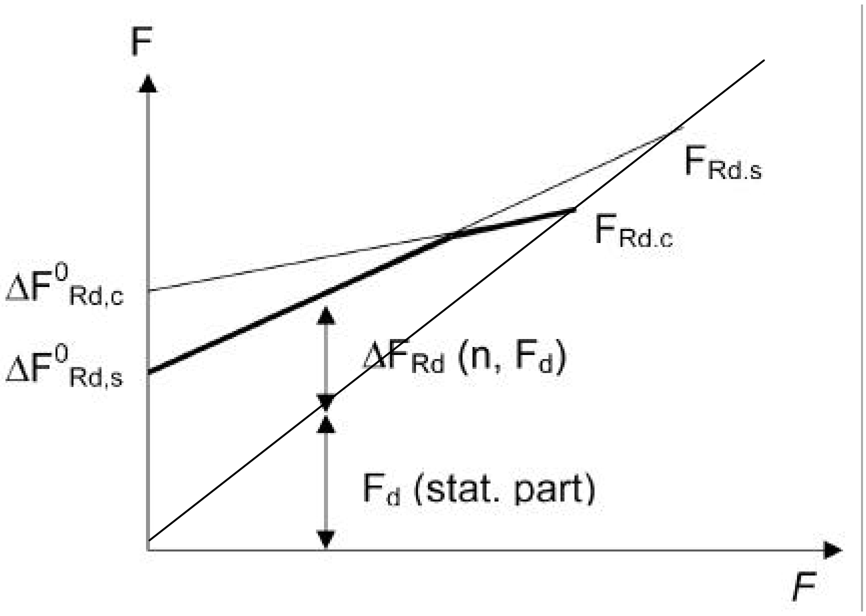
In general the fatigue design should be done for the fatigue-relevant part of the external force ΔF and the relevant number of load cycles n.

$\Delta F_{R,d}(n) > \Delta F_d$

For simplified design the number of load cycles is n≥2'000'000 and the total load is fatigue-relevant.

Identification of fatigue resistances

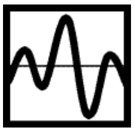
For tensile and shear forces the resistances for steel and concrete fatigue should be determined. These values ($\Delta N_{Rd,s}$, $\Delta N_{Rd,c}$, $\Delta V_{Rd,s}$, $\Delta V_{Rd,c}$) are identified with tests for each number of load cycles (Wöhler Curves).



$$\Delta N_{Rd} = \min \begin{Bmatrix} \Delta N^0_{Rd,s} + (N_{Rd,s} - \Delta N^0_{Rd,s}) \cdot \dfrac{N_d}{N_{Rd,s}} - N_d \\ \Delta N^0_{Rd,c} + (N_{Rd,c} - \Delta N^0_{Rd,c}) \cdot \dfrac{N_d}{N_{Rd,c}} - N_d \end{Bmatrix}$$

$$\Delta N_{Rd} = \min \begin{Bmatrix} \Delta N^0_{Rd,s} + (N_{Rd,s} - \Delta N^0_{Rd,s}) \cdot \dfrac{N_d}{N_{Rd,s}} - N_d \\ \Delta N^0_{Rd,c} + (N_{Rd,c} - \Delta N^0_{Rd,c}) \cdot \dfrac{N_d}{N_{Rd,c}} - N_d \end{Bmatrix}$$

For group fastenings a group factor has be taken into account, which gives the reduction due to load redistribution from the more flexible to the stiffer anchors.



Earthquakes (seismic loading)

External load

To determine the exact external load on an anchor during an earthquake is very difficult. For this reason most of the national and international regulations deal with earthquakes based on a statical action multiplied with a seismic amplification factor. During an earthquake the lateral forces caused by the lateral acceleration is often most critical.

Anchor design

The behaviour of anchors under seismic action depends on the magnitude of loading, the direction of loading, the base material and the type of anchor.

Thus it is very important to compare the testing procedures for the anchors with the assumptions for the external loading. An overall design procedure cannot be given.

There is a large number of anchors, that have been tested according to different procedures (ICBO, CAN/CSA, KEPCO, ENEL, Bechtel, Sweep1, Sweep2 . The test results therefore only are valid for the assumptions for the particular test procedures.

To achieve UBC (Uniform Building Code) compliance Hilti Anchors are tested according to the ICBO ES AC01 (HDA, HSL, KB-II) and AC58 (HVA). The UBC 1997 has provisions for both Strength Design (comparable to load resistance comparison on design level according to EC) and allowable Stress Design (comparison of load and resistance on working load level). For these two different design methods different load combinations with different safety factors are provided for the design engineer. to take into consideration.

Following the ICBO ES seismic method 2 test, the static loading capacity is then tested for and must attain a minimum of 80% of control anchors, statically tested in the same concrete block, average ultimate capacity. Displacement limitations are also required by the criteria.

Impact and shock-like loads

For the shock design it is very important to define the admissible deformations and the actions that have to be taken after the shock event.
If only elastic deformations are allowed (no permanent deformations) after rhe shock incident, the static resistances of the anchor are also suitable for shock. This leads often to a non-economic anchor selection. To avoid this, different regulations allow plastic deformations on condition that the anchors are replaced after the shock incident. Under this assumption the shock resistances are much higher (e.g. shock resistances according to BZS regulations given in chapter 6).
According to German regulations the resistance of expansion anchors can be increased to 1.7 times the static resistance; for undercut anchors the shock resistance is even 2.7 times the static resistance (compared to DIBt-approved static resistance).

4. Productinformation Fatigue Resistances

The following anchor resistances for tensile, shear and combined loads are the approved values from the DIBt (Deutsches Institut für Bautechnik). This Productinformation is only valid together with the general Productinformation given in the Fastening Technology Manual FTM.

In addition to this the dynamic set (Appendix A) has to be used.

For the design the following assumptions have to be taken into consideration:

- all applied loads are fatigue relevant
- load safety factor γ_F=1.0
- for group fixings a group factor has to be considered (redistribution of loads in the anchor group)
- number of load cycles n≥2'000'000
- design with reduced anchor spacings, edge distances or other concrete qualities is done according Hilti-cc-method (Hilti concrete capacity method: simplified method acc. to ETAG annex C)
- the concrete resistance has to be reduced

4.1 Productinformation HDA

Basic load data (for a single anchor): HDA-P (n≥2'000'000)

steel failure in cracked and uncracked concrete:

Characteristic resistance ΔR_k [kN]: concrete C20/25 (according DIBt)

Anchor size	M10	M12	M16
Tensile $\Delta N_{Rk,s}$	10.1	17.7	34.4
Shear $\Delta V_{Rk,s}$	2.74	5.94	8.18

γ_{MsN}=1.5; γ_{MsV}=1.35 material safety factors acc. to DIBt approval

Design resistance ΔR_d [kN]: concrete $f_{ck,cube}$ =25 N/mm^2

Anchor size	M10	M12	M16
Tensile $\Delta N_{Rd,s}$	6.7	11.8	22.9
Shear $\Delta V_{Rd,s}$	2.0	4.4	6.1

Group factors: Tension: $\gamma_{F,N}$ / Shear: $\gamma_{F,V}$ **$\gamma_{F,N}$=$\gamma_{F,V}$=1.0 for single anchor**
$\gamma_{F,N}$= 1.3 $\gamma_{F,V}$=1.2 for more than one anchor

Basic load data (for a single anchor): HDA-T (n≥2'000'000)

steel failure in cracked and uncracked concrete:

Characteristic resistance ΔR_k [kN]: concrete C20/25 (according DIBt)

Anchor size	M10	M12	M16
Tensile $\Delta N_{Rk,s}$	10.1	17.7	34.4
Shear $\Delta V_{Rk,s}$	8.52	15.3	23.3

γ_{MsN}=1.5; γ_{MsV}=1.35 material safety factors acc. to DIBt approval

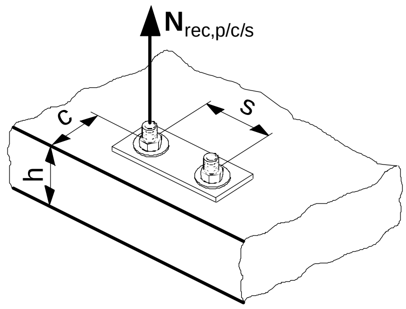
Design resistance ΔR_d [kN]: concrete $f_{ck,cube}$ =25 N/mm^2

Anchor size	M10	M12	M16

Tensile $\Delta N_{Rd,s}$	6.7	11.8	22.9
Shear $\Delta V_{Rd,s}$	6.3	11.3	17.3

Detailed design method - Hilti CC

(The Hilti CC-Method is a simplified Version of ETAG Annex C)



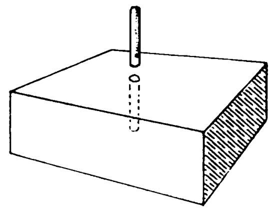
TENSION

The tensile **design** resistance of a single anchor is the minimum of:

- $\Delta N_{Rd,p}$: concrete pull out resistance (only in cracked concrete)
- $\Delta N_{Rd,c}$: concrete cone resistance
- $\Delta N_{Rd,s}$: steel resistance

$N_{Rd,p}$: Concrete pull-out resistance (only in cracked concrete)

$$\Delta N_{Rd,p} = \Delta N^{o}_{Rd,p} \cdot f_B$$



$\Delta N^{0}_{Rd,p}$ [1)] : Concrete pull-out design resistance

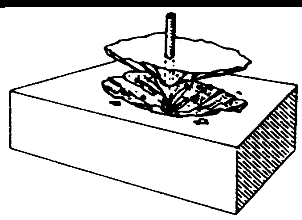
- concrete compressive strength $f_{ck,cube(150)}$ = 25 N/mm²

Anchor size	**HDA-T/HDA-P**	**M10**	**M12**	**M16**
$\Delta N^{0}_{Rd,p}$ [kN]	in cracked concrete	9.9	13.8	29.6

1) The initial value of the tensile design load against pull out is calculated from $\Delta N°_{Rd,p} = \Delta N°_{Rk,p}/\gamma_{Mc}$, where the partial safety factor for concrete is γ_{Mc}=1.62, with $\Delta N°_{Rk,p}$ =64%$N_{Rk,p}$. The load values are corresponding to a constant load. The displacement is smaller than $d_{95\%} \leq$ 3 mm after 1000 crack cycles (w = 0.3 mm).

$\Delta N_{Rd,c}$: Concrete cone resistance

$$\Delta N_{Rd,c} = \Delta N^{o}_{Rd,c} \cdot f_B \cdot f_{A,N} \cdot f_{R,N}$$



$\Delta N^{0}_{Rd,c}$: Concrete cone design resistance

- concrete compressive strength $f_{ck,cube(150)}$ = 25 N/mm²

Anchor size	**HDA-T/HDA-P**	**M10**	**M12**	**M16**
$\Delta N^{0}_{Rd,c}$ [1)] [kN]	in cracked concrete w = 0.3mm	16.4	22.9	42.9

1) The value of the tensile design load against concrete coin failure is calculated from $\Delta N°_{Rd,c} = \Delta N°_{Rk,c}/\gamma_{Mp}$, where the partial safety factor for concrete is γ_{Mc}=1.62, with $\Delta N°_{Rk,c}$=64%$N°_{Rd,c}$

f_B : Influence of concrete strength

Concrete strength designation (ENV 206)	Cylinder compressive strength $f_{ck,cyl}$ [N/mm²]	**Cube compressive strength $f_{ck,cube}$ [N/mm²]**	**f_B**
C20/25	20	**25**	**1**
C25/30	25	**30**	**1.1**
C30/37	30	**37**	**1.22**
C35/45	35	**45**	**1.34**
C40/50	40	**50**	**1.41**
C45/55	45	**55**	**1.48**
C50/60	50	**60**	**1.55**

Concrete cylinder: height 30cm, 15cm diameter	Concrete cube: side length 15cm
Concrete test specimen geometry	

$$f_B = \sqrt{\frac{f_{ck,cube}}{25}}$$

Limits:
25 N/mm² $\leq f_{ck,cube} \leq$ 60 N/mm²

$f_{A,N}$: Influence of anchor spacing,

Anchor spacing s [mm]	HDA-T/HDA-P anchor size		
	M10	M12	M16
100	0.67		
125	0.71	0.67	
150	0.75	0.70	
190	0.82	0.75	0.67
200	0.83	0.77	0.68
250	0.92	0.83	0.72
300	1.00	0.90	0.76
350		0.97	0.81
375		1.00	0.83
400			0.85
450			0.89
500			0.94
550			0.98
570			1.00

$$f_{A,N} = 0.5 + \frac{s}{6 \cdot h_{ef}}$$

Limits: $s_{min} \leq s \leq s_{cr,N}$

$s_{min} = h_{ef}$

$s_{cr,N} = 3 \cdot h_{ef}$

$f_{R,N}$: Influence of edge distance,

Edge distance c [mm]	HDA-T/HDA-P anchor size		
	M10	M12	M16
80	0.66		
100	0.76	0.66	
120	0.86	0.74	
140	0.96	0.82	
150	1.00	0.87	0.66
160		0.90	0.68
180		0.98	0.73
187		1.00	0.75
200			0.79
220			0.84
240			0.89
260			0.94
280			0.99
285			1.00

$$f_{R,N} = 0.27 + 0.49 \cdot \frac{c}{h_{ef}}$$

Limits: $c_{min} \leq c \leq c_{cr,N}$

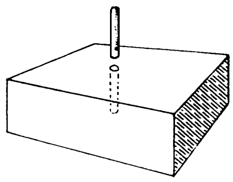
$c_{min} = 0.8 \cdot h_{ef}$

$c_{cr,N} = 1.5 \cdot h_{ef}$

Note: If more than 3 edges are smaller than $c_{cr,N}$ consult your Hilti Technical Advisory Service

$\Delta N_{Rd,s}$: Steel tensile design resistance

Anchor size HDA-T/HDA-P	M10	M12	M16
$\Delta N_{Rd,s}$ 1) [kN]	6.7	11.8	22.9



ΔN_{Rd} : System tensile design resistance

ΔN_{Rd} = minimum of $\Delta N_{Rd,p}$, $\Delta N_{Rd,c}$ and $\Delta N_{Rd,s}$

Combined load: see page 24

PI Fatigue HDA

Detailed design method – Hilti CC

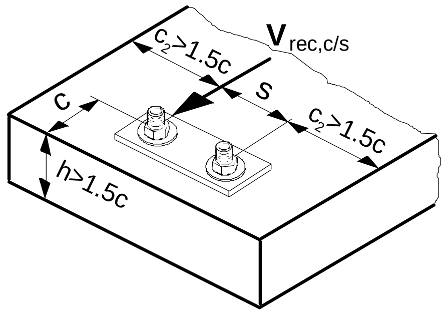
(The Hilti CC-Method is a simplified Version of ETAG Annex C)

SHEAR

The design shear resistance of a single anchor is the minimum of:

$\Delta V_{Rd,c}$: concrete edge resistance

$\Delta V_{Rd,s}$: steel resistance

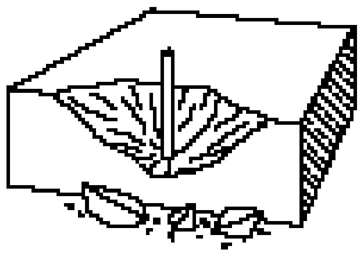


Note: If the conditions regarding h and c_2 are not met, consult your **Hilti technical advisory service.**

$\Delta V_{Rd,c}$: Concrete edge design resistance

The weakest concrete edge resistance must be calculated. All nearby edges must be checked, (not only the edge in the direction of shear). Shear direction is accounted for by the factor $f_{\beta,V}$.

$$\Delta V_{Rd,c} = \Delta V^{o}_{Rd,c} \cdot f_B \cdot f_{b,V} \cdot f_{AR,V}$$



$\Delta V^0_{Rd,c}$: Concrete edge design resistance

- concrete compressive strength $f_{ck,cube(150)}$ = 25 N/mm^2
- at minimum edge distance $\mathbf{c}_{min}$

Anchor size	HDA-T/HDA-P	M10	M12	M16
$\Delta V^0_{Rd,c}$ [1)]	[kN] in cracked concrete w = 0.3 mm	3.1	4.6	9.5
$\Delta V^0_{Rd,c}$ [1)]	[kN] in uncracked concrete	4.3	6.5	13.3
c_{min} [mm]	cracked and non-cracked concrete	80	100	150

1) The design value of the ultimate state in shear is calculated from the characteristic anchor shear resistance, $\Delta V^{\circ}_{Rk,c}$, divided by $\Delta V^{\circ}_{Rd,c} = \Delta V^{\circ}_{Rk,c}/\gamma_{Mc,V}$, where the partial safety factor, $\gamma_{Mc,V}$, is 1.62 and $\Delta V_{Rk,c}$=55%$V_{Rk,c}$

f_B : Influence of concrete strength

Concrete strength designation (ENV 206)	Cylinder compressive strength $f_{ck,cyl}$ [N/mm²]	**Cube compressive strength $f_{ck,cube}$ [N/mm²]**	f_B
C20/25	20	**25**	**1**
C25/30	25	**30**	**1.1**
C30/37	30	**37**	**1.22**
C35/45	35	**45**	**1.34**
C40/50	40	**50**	**1.41**
C45/55	45	**55**	**1.48**
C50/60	50	**60**	**1.55**

Concrete cylinder: height 30cm, 15cm diameter	Concrete cube: side length 15cm
Concrete test specimen geometry	

Limits: 25 N/mm^2 $\le f_{ck,cube} \le$ 60 N/mm^2

$$f_B = \sqrt{\frac{f_{ck,cube}}{25}}$$

$f_{\beta,V}$: Influence of shear load direction

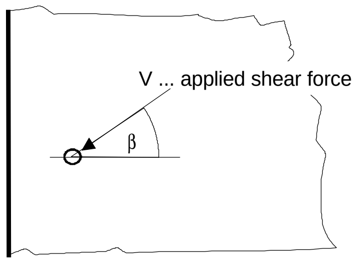
Angle β [°]	$f_{\beta,V}$
0 to 55	**1**
60	**1.1**
70	**1.2**
80	**1.5**
90 to 180	**2**

Formulae:

$$f_{\beta,V} = 1 \qquad \text{for } 0° \le \beta \le 55°$$

$$f_{\beta,V} = \frac{1}{\cos\beta + 0.5\sin\beta} \qquad \text{for } 55° < \beta \le 90°$$

$$f_{\beta,V} = 2 \qquad \text{for } 90° < \beta \le 180°$$



$f_{AR,V}$: Influence of spacing and edge

Formula for **single** anchor influenced only by edge

$$f_{AR,V} = \frac{c}{c_{min}} \sqrt{\frac{c}{c_{min}}}$$

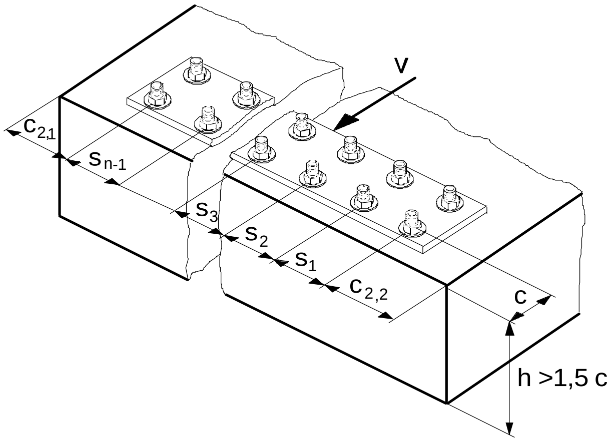
Formula for anchor **pair** valid for s < 3c

$$f_{AR,V} = \frac{3c + s}{6c_{min}} \sqrt{\frac{c}{c_{min}}}$$

results tabulated below

General formula for **n** anchors (edge plus n-1 spacing) only valid where s_1 to s_{n-1} are all < 3c

$$f_{AR,V} = \frac{3c + s_1 + s_2 + \ldots + s_{n-1}}{3nc_{min}} \cdot \sqrt{\frac{c}{c_{min}}}$$



It is **important** that the base plate is designed and installed such that the applied shear is distributed onto all anchors, as assumed in these calculations

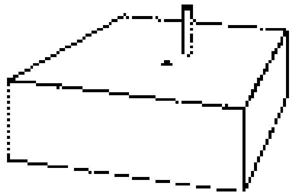
If $c_{2,1}$ or $c_{2,2}$ or h are less than 1.5c reductions apply, please contact the Hilti Technical Advisory Service

$f_{AR,V}$		c/c_{min} →															
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
Single anchor with edge influence		1.00	1.31	1.66	2.02	2.41	2.83	3.26	3.72	4.19	4.69	5.20	5.72	6.27	6.83	7.41	8.00
s/c_{min} ↓	1.0	0.67	0.84	1.03	1.22	1.43	1.65	1.88	2.12	2.36	2.62	2.89	3.16	3.44	3.73	4.03	4.33
	1.5	0.75	0.93	1.12	1.33	1.54	1.77	2.00	2.25	2.50	2.76	3.03	3.31	3.60	3.89	4.19	4.50
	2.0	0.83	1.02	1.22	1.43	1.65	1.89	2.13	2.38	2.63	2.90	3.18	3.46	3.75	4.05	4.35	4.67
	2.5	0.92	1.11	1.32	1.54	1.77	2.00	2.25	2.50	2.77	3.04	3.32	3.61	3.90	4.21	4.52	4.83
	3.0	1.00	1.20	1.42	1.64	1.88	2.12	2.37	2.63	2.90	3.18	3.46	3.76	4.06	4.36	4.68	5.00
	3.5		1.30	1.52	1.75	1.99	2.24	2.50	2.76	3.04	3.32	3.61	3.91	4.21	4.52	4.84	5.17
	4.0			1.62	1.86	2.10	2.36	2.62	2.89	3.17	3.46	3.75	4.05	4.36	4.68	5.00	5.33
	4.5				1.96	2.21	2.47	2.74	3.02	3.31	3.60	3.90	4.20	4.52	4.84	5.17	5.50
	5.0					2.33	2.59	2.87	3.15	3.44	3.74	4.04	4.35	4.67	5.00	5.33	5.67
	5.5						2.71	2.99	3.28	3.57	3.88	4.19	4.50	4.82	5.15	5.49	5.83
	6.0						2.83	3.11	3.41	3.71	4.02	4.33	4.65	4.98	5.31	5.65	6.00
	6.5							3.24	3.54	3.84	4.16	4.47	4.80	5.13	5.47	5.82	6.17
	7.0								3.67	3.98	4.29	4.62	4.95	5.29	5.63	5.98	6.33
	7.5									4.11	4.43	4.76	5.10	5.44	5.79	6.14	6.50
	8.0										4.57	4.91	5.25	5.59	5.95	6.30	6.67
	8.5											5.05	5.40	5.75	6.10	6.47	6.83
	9.0											5.20	5.55	5.90	6.26	6.63	7.00
	9.5												5.69	6.05	6.42	6.79	7.17
	10.0													6.21	6.58	6.95	7.33
	10.5														6.74	7.12	7.50
	11.0															7.28	7.67
	11.5																7.83
	12.0																8.00

These results are for a pair of anchors.

For more than 2 anchors, use the general formulae for n anchors at the top of the page.

$\Delta V_{Rd,s}$: Steel design shear resistance



Anchor size			M10	M12	M16
$\Delta V_{Rd,s}$	[kN]	HDA-T	6.3	11.3	17.3
		HDA-P	2.0	4.4	6.1

1) The shear design resistance is calculated from $\Delta V_{Rd,s} = \Delta V_{Rk,s}/\gamma_{Ms,V}$. The partial safety factor $\gamma_{Ms,V}$ for HDA-T is equal to 1.5 and 1.25 for HDA-P.

ΔV_{Rd} : System design shear resistance

ΔV_{Rd} = minimum of $V_{Rd,c}$ and $V_{Rd,s}$

COMBINED LOADS

steel: $$\frac{\gamma_{F,N} \cdot \Delta N^{h}_{Sd}}{\frac{\Delta N_{Rk,s}}{\gamma_{MsN}}} + \frac{\gamma_{F,V} \cdot \Delta V^{h}_{Sd}}{\frac{\Delta V_{Rk,s}}{\gamma_{MsV}}} \leq 1.0$$ **highest loaded single anchor**

concrete: $$\frac{\Delta N^{g}_{Sd}}{\left(\frac{\Delta N^{g}_{Rk,c}}{\gamma_{Mc}}\right)} + \frac{\Delta V^{g}_{Sd}}{\left(\frac{\Delta V^{g}_{Rk,c}}{\gamma_{Mc}}\right)} \leq 1.0$$ **anchor group**

4.2 Productinformation HVZ

Basic load data (for a single anchor): HAS-TZ

steel failure in cracked and uncracked concrete

Characteristic resistance R_k [kN]: concrete C20/25 (according DIBt)

Anchor size	M10x75	M12x95	M16x105	M16x125	M20x170
Tensile $\Delta N_{Rk,s}$	10.5	19.8	21.1	27.6	27.6
Shear $\Delta V_{Rk,s}$	3.9	6.9	12.4	12.4	12.4

Design resistance R_d [kN]: concrete $f_{ck,cube}$ =25 N/mm^2

Anchor size	M10x75	M12x95	M16x105	M16x125	M20x170
Tensile $\Delta N_{Rd,s}$	8.1	14.7	15.6	15.6	15.6
Shear $\Delta V_{Rd,s}$	3.6	6.3	11.3	11.3	11.3

Group factors: Tension: $\gamma_{F,N}$ / Shear: $\gamma_{F,V}$ **$\gamma_{F,N}=\gamma_{F,V}$=1.0 for single anchor**
$\gamma_{F,N}$= 1.45 $\gamma_{F,V}$=1.3 for more than one anchor

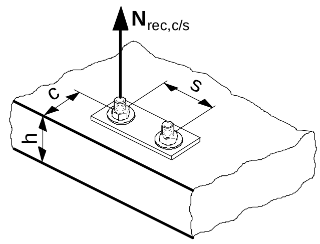
TENSION

The tensile **design** resistance of a single anchor is the minimum of,

$\Delta N_{Rd,p}$: concrete pull-out resistance

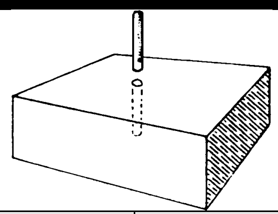
$\Delta N_{Rd,c}$: concrete cone resistance

$\Delta N_{Rd,s}$: steel resistance



$\Delta N_{Rd,p}$: Concrete pull-out resistance

$$\Delta N_{Rd,p} = \Delta N^{o}_{Rd,p} \cdot f_B$$



$\Delta N^0_{Rd,p}$ 1) : Concrete pull-out design resistance

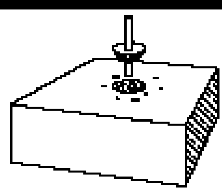
concrete compressive strength $f_{ck,cube(150)}$ = 25 N/mm^2

Anchor size	HVZ	M10x75	M12x95	M16x105	M16x125	M20x170
$\Delta N^0_{Rd,p}$ [kN]	in cracked concrete	5.3	10.8	12.5	15.5	29.4
$\Delta N^0_{Rd,p}$ [kN]	in uncracked concrete	6.6	12.5	15.5	18.6	35.6

1) The initial value of the tensile design load against pull out is calculated from $\Delta N°_{Rd,p}=\Delta N°_{Rk,p}/\gamma_{Mp}$, where the partial safety factor for concrete is γ_{Mp}=2.27 (M10) resp. 1.94 (M12, M16, M20), with $\Delta N°_{Rk,p}$ =60%$N_{Rk,p}$. The load values are corresponding to a constant load. The displacement is smaller than $d_{95\%} \leq$ 3 mm after 1000 crack cycles (w = 0.3 mm).

$\Delta N_{Rd,c}$: Concrete cone resistance

$$\Delta N_{Rd,c} = \Delta N^0_{Rd,c} \cdot f_{B.N} \cdot f_{A,N} \cdot f_{R,N}$$



$\Delta N^0_{Rd,c}$:Concrete cone/pull-out design resistance

concrete compressive resistance: $f_{ck,cube(150)}$=25N/mm^2

Anchor Size		M10x75	M12x95	M16x105	M16x125	M20x170
$\Delta N^0_{Rd,c}$ 1) [kN]	in non-cracked concrete	12.1	17.3	20.1	26.1	41.4
$\Delta N^0_{Rd,c}$ 1) [kN]	in cracked concrete	8.7	12.3	14.3	18.6	29.6
h_{ef} [mm]	Actual anchorage depth	75	95	105	125	170

[1] The tensile design resistance is calculated from the tensile characteristic resistance $\Delta N^{o}_{Rk,c}$=60%$N_{Rk,c}$ by $\Delta N^{o}_{Rd,c}$= $\Delta N^{o}_{Rk,c}/\gamma_{Mc,N}$, where the partial safety factor $\gamma_{Mc,N}$ is equal to 1.62.

PI Fatigue HVZ

$f_{B,N}$:Influence of concrete strength

Designation of grade of concrete (ENV 206)	Cylinder compressive strength, $f_{ck,cyl}$ [N/mm²]	**Cube compressive strength, $f_{ck,cube}$ [N/mm²]**	$f_{B,N}$	
			M10 | M12	**M16 | M20**
C20/25	20	**25**	**1**	**1**
C25/30	25	**30**	**1.03**	**1.07**
C30/37	30	**37**	**1.06**	**1.17**
C35/45	35	**45**	**1.10**	**1.29**
C40/50	40	**50**	**1.13**	**1.36**
C45/55	45	**55**	**1.15**	**1.43**
C50/60	50	**60**	**1.18**	**1.51**

Concrete cylinder: height 30cm, 15cm diameter	Concrete cube: side length 15cm
Concrete test specimen geometry	

K = 197.5 for M10 and M12
K = 68.75 for M16 and M20

$$f_{B,N} = 1 + \left(\frac{f_{ck,cube} - 25}{K}\right)$$

Limits: 25 N/mm² $\leq f_{ck,cube} \leq$ 60 N/mm²

$f_{A,N}$: Influence of spacing

Spacing, s [mm]	Anchor size				
	M10	**M12**	**M16**	**M16L**	**M20**
60	0.63				
65	0.64				
70	0.66				
75	0.67	0.63			
80	0.68	0.64			
85	0.69	0.65	0.63	0.61	
90	0.70	0.66	0.64	0.62	
100	0.72	0.68	0.66	0.63	
120	0.77	0.71	0.69	0.66	
135	0.80	0.74	0.71	0.68	0.63
140	0.81	0.75	0.72	0.69	0.64
160	0.86	0.78	0.75	0.71	0.66
180	0.90	0.82	0.79	0.74	0.68
200	0.94	0.85	0.82	0.77	0.70
220	1.00	0.89	0.85	0.79	0.72
240		0.92	0.88	0.82	0.74
270		0.97	0.93	0.86	0.76
300		1.00	0.98	0.90	0.79
330			1.00	0.94	0.82
360				0.98	0.85
390				1.00	0.88
420					0.91
450					0.94
480					0.97
510					1.00

$$f_{A,N} = 0.5 + \frac{s}{6h_{ef}}$$

Limits: $s_{min} \leq s \leq s_{cr,N}$

Anchor size	M10	M12	M16	M16L	M20
s_{min} [mm]	60	75	85		135
$s_{cr,N}$ [mm]	225	285	315	375	510

$f_{R,N}$: Influence of edge distance

Edge distance, c [mm]	Anchor size				
	M10	**M12**	**M16**	**M16L**	**M20**
60	0.65				
65	0.68				
70	0.72				
75	0.75	0.64			
80	0.78	0.67			
85	0.82	0.70	0.65	0.59	
90	0.85	0.72	0.68	0.61	
95	0.88	0.75	0.70	0.63	
100	0.92	0.78	0.73	0.65	
105	0.95	0.80	0.75	0.67	
110	0.98	0.83	0.77	0.69	
115	1.00	0.86	0.80	0.71	
125		0.91	0.85	0.75	
135		0.96	0.89	0.79	0.65
145		1.00	0.94	0.83	0.68
155			1.00	0.87	0.71
165				0.91	0.74
175				0.95	0.76
185				1.00	0.79
205					0.85
230					0.93
255					1.00

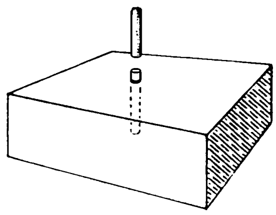
$$f_{R,N} = 0.25 + 0.50 \frac{c}{h_{ef}}$$

Limits: $c_{min} \leq c \leq c_{cr,N}$

Anchor size	M10	M12	M16	M16L	M20
c_{min} [mm]	60	75	85		135
$c_{cr,N}$ [mm]	113	143	158	188	255

Note: If more than 3 edge distances are smaller than $c_{cr,N}$, please contact your Hilti sales representative.

$\Delta N_{Rd,s}$: Steel tensile design resistance



Anchor size	**M10x75**	**M12x95**	**M16x105**	**M16x125**	**M20x170**
$\Delta \mathbf{N}_{Rd,s}$ [1)] [kN] HAS-TZ steel grade 8.8	8.1	14.7	15.6	15.6	15.6

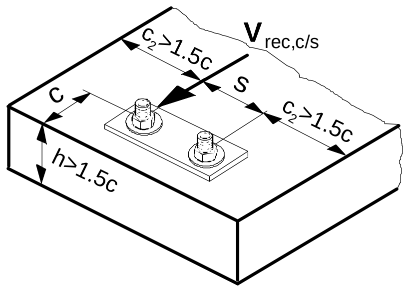
1) The partial safety factor, $\gamma_{Ms,N}$ =1.35.

SHEAR

The design shear resistance of a single anchor is the minimum of,

$\Delta V_{Rd,c}$: concrete edge resistance

$\Delta V_{Rd,s}$: steel resistance

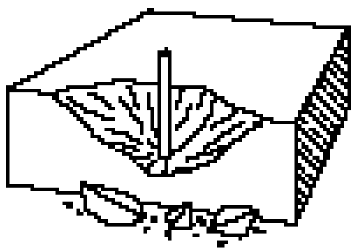


Note: If the conditions shown for h and c_2 cannot be observed, please contact your Hilti sales representative.

$\Delta V_{Rd,c}$: Concrete edge design resistance

The weakest concrete edge resistance must be calculated. All nearby edges must be checked, (not only the edge in the direction of shear). Shear direction is accounted by the factor $f_{\beta,V}$.

$$\Delta V_{Rd,c} = \Delta V^{0}_{Rd,c} \cdot f_{B,V} \cdot f_{b,V} \cdot f_{AR,V}$$



$\Delta V^{0}_{Rd,c}$: Concrete edge design resistance

- concrete compressive strength $f_{ck,cube(150)} = 25$ N/mm^2
- at minimum edge distance c_{min}

Anchor size			M10x75	M12x95	M16x105	M16x125	M20x170
$\Delta V^{0}_{Rd,c}$ 1)	[kN]	in non-cracked concrete	2.6	4.0	5.3	5.5	12.6
$\Delta V^{0}_{Rd,c}$ 1)	[kN]	in cracked concrete	1.8	2.8	3.8	3.9	9.0
c_{min}	[mm]	Min. edge distance	60	75	85		135

1) The design value of the ultimate state in shear is calculated from the characteristic anchor shear resistance, $\Delta V°_{Rk,c}$=60% $V°_{Rk,c}$ divided by $\gamma_{Mc,V}$, where the partial safety factor, $\gamma_{Mc,V}$, is 1.62.

$f_{B,V}$: Influence of concrete strength

Concrete strength designation (ENV 206)	Cylinder compressive strength $f_{ck,cyl}$ [N/mm²]	**Cube compressive strength $f_{ck,cube}$ [N/mm²]**	$f_{B,V}$
C20/25	20	**25**	**1**
C25/30	25	**30**	**1.1**
C30/37	30	**37**	**1.22**
C35/45	35	**45**	**1.34**
C40/50	40	**50**	**1.41**
C45/55	45	**55**	**1.48**
C50/60	50	**60**	**1.55**

Concrete cylinder: height 30cm, 15cm diameter	Concrete cube: side length 15cm
Concrete test specimen geometry	

$$f_{B,V} = \sqrt{\frac{f_{ck,cube}}{25}}$$

Limits: 25 N/mm^2 $\le f_{ck,cube} \le$ 60 N/mm^2

$f_{\beta,V}$: Influence of shear load direction

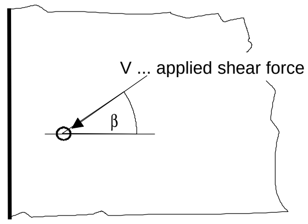
Angle β [°]	$f_{\beta,V}$
0 to 55	**1**
60	**1.1**
70	**1.2**
80	**1.5**
90 to 180	**2**

Formulae:

$f_{\beta,V} = 1$ for $0° \leq \beta \leq 55°$

$f_{\beta,V} = \frac{1}{\cos\beta + 0.5\sin\beta}$ for $55° < \beta \leq 90°$

$f_{\beta,V} = 2$ for $90° < \beta \leq 180°$



$f_{AR,V}$: Influence of spacing and edge

Formula for **single** anchor influenced only by edge

$$f_{AR,V} = \frac{c}{c_{min}}\sqrt{\frac{c}{c_{min}}}$$

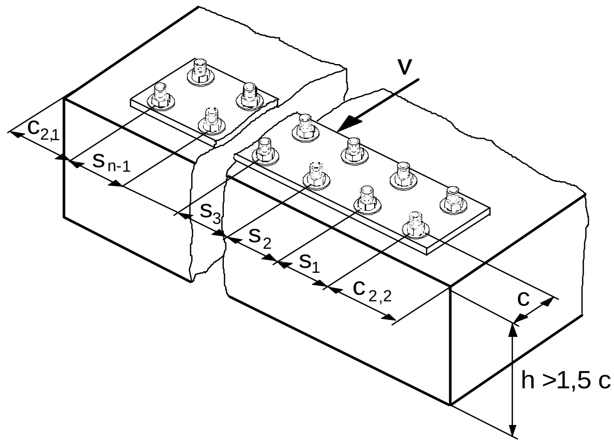
Formula for anchor **pair** valid for s < 3c

$$f_{AR,V} = \frac{3c + s}{6c_{min}}\sqrt{\frac{c}{c_{min}}}$$

results tabulated below

General formula for **n** anchors (edge plus n-1 spacing) only valid where s_1 to s_{n-1} are all < 3c

$$f_{AR,V} = \frac{3c + s_1 + s_2 + ... + s_{n-1}}{3nc_{min}} \cdot \sqrt{\frac{c}{c_{min}}}$$



Note: It is assumed that only the row of anchors closest to the free concrete edge carries the centric shear load

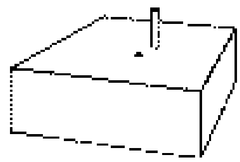
$f_{AR.V}$		c/c_{min} →															
		1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.8	4.0
Single anchor with edge influence		1.00	1.31	1.66	2.02	2.41	2.83	3.26	3.72	4.19	4.69	5.20	5.72	6.27	6.83	7.41	8.00
s/c_{min} ↓	1.0	0.67	0.84	1.03	1.22	1.43	1.65	1.88	2.12	2.36	2.62	2.89	3.16	3.44	3.73	4.03	4.33
	1.5	0.75	0.93	1.12	1.33	1.54	1.77	2.00	2.25	2.50	2.76	3.03	3.31	3.60	3.89	4.19	4.50
	2.0	0.83	1.02	1.22	1.43	1.65	1.89	2.13	2.38	2.63	2.90	3.18	3.46	3.75	4.05	4.35	4.67
	2.5	0.92	1.11	1.32	1.54	1.77	2.00	2.25	2.50	2.77	3.04	3.32	3.61	3.90	4.21	4.52	4.83
	3.0	1.00	1.20	1.42	1.64	1.88	2.12	2.37	2.63	2.90	3.18	3.46	3.76	4.06	4.36	4.68	5.00
	3.5		1.30	1.52	1.75	1.99	2.24	2.50	2.76	3.04	3.32	3.61	3.91	4.21	4.52	4.84	5.17
	4.0			1.62	1.86	2.10	2.36	2.62	2.89	3.17	3.46	3.75	4.05	4.36	4.68	5.00	5.33
	4.5				1.96	2.21	2.47	2.74	3.02	3.31	3.60	3.90	4.20	4.52	4.84	5.17	5.50
	5.0					2.33	2.59	2.87	3.15	3.44	3.74	4.04	4.35	4.67	5.00	5.33	5.67
	5.5						2.71	2.99	3.28	3.57	3.88	4.19	4.50	4.82	5.15	5.49	5.83
	6.0						2.83	3.11	3.41	3.71	4.02	4.33	4.65	4.98	5.31	5.65	6.00
	6.5							3.24	3.54	3.84	4.16	4.47	4.80	5.13	5.47	5.82	6.17
	7.0								3.67	3.98	4.29	4.62	4.95	5.29	5.63	5.98	6.33
	7.5									4.11	4.43	4.76	5.10	5.44	5.79	6.14	6.50
	8.0										4.57	4.91	5.25	5.59	5.95	6.30	6.67
	8.5											5.05	5.40	5.75	6.10	6.47	6.83
	9.0											5.20	5.55	5.90	6.26	6.63	7.00
	9.5												5.69	6.05	6.42	6.79	7.17
	10.0													6.21	6.58	6.95	7.33
	10.5														6.74	7.12	7.50
	11.0															7.28	7.67
	11.5																7.83
	12.0																8.00

These results are for a pair of anchors.

For more than 2 anchors, use the general formulae for n anchors at the top of the page.

$\Delta V_{Rd,s}$: Steel design shear resistance

Anchor size		M10x75	M12x95	M16x105	M16x125	M20x170
$\Delta V_{Rd,s}$[1)] [kN]	HAS-TZ steel grade 8.8	3.6	6.3	11.3	11.3	11.3



1) The design shear resistance is calculated using $\Delta V_{Rd,s} = V_{Rk,s}/\gamma_{Ms,V}$.

ΔV_{Rd} : System shear design resistance

ΔV_{Rd} = minimum of $\Delta V_{Rd,c}$ and $\Delta V_{Rd,s}$

COMBINED LOADS

steel:

$$\left(\frac{g_{F,N} \cdot \Delta N_{Sd}^{h}}{\frac{\Delta N_{Rk,s}}{g_{MsN}}}\right)^{a} + \left(\frac{g_{F,V} \cdot \Delta V_{Sd}^{h}}{\frac{\Delta V_{Rk,s}}{g_{MsV}}}\right)^{a} \leq 1.0$$

highest loaded single anchor

with α=0.76 (M10); α=0.87 (M12); α=1.0 (M16, M20) concrete: $$\frac{\Delta N^{g}_{Sd}}{\left(\frac{\Delta N^{g}_{Rk,c}}{g_{Mc}}\right)} + \frac{\Delta V^{g}_{Sd}}{\left(\frac{\Delta V^{g}_{Rk,c}}{g_{Mc}}\right)} \leq 1.0$$ anchor group

5. Productinformation Seismic

As described already in chapter 3 the anchor resistances depend a lot on the assumptions of testing and the assumptions for the determination of the loads. There are a lot of national and international codes that have to be respected.
ICBO Evaluation reports give the anchor resistances for the strength design and or for allowable stress method described in UBC 1997. For the following anchors Evaluation Reports, which allow seismic design are available (download from Internet www.ICBO.org):

HDA: ER-5608 issued April 1, 2000
KB-II: ER-4627 issued July 1, 1998
HSL: ER-3987 reissued July 1, 1998
HVA: ER-5369 reissued March 1, 2000

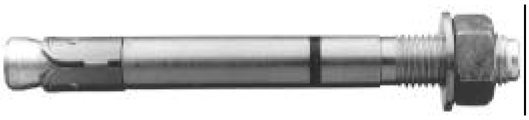
For allowable stress design method it's allowed to increase the statical resistances by $33\frac{1}{3}\%$.

For design strength method the higher resistances are included in the load safety factors.

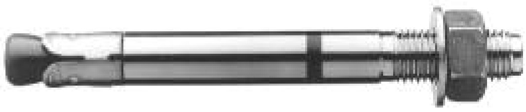
6. Productinformation Shock Resistances

The following anchor resistances and anchor spacing informations are the approved values from the BZS (Bundesamt für Zivilschutz: Swiss Authority for Civil Defence). This Productinformation is only valid together with the general Productinformation given in the Fastening Technology Manual FTM.
For shear loads and for combined loads the same resistances are applicable.
The anchor resistance values are for concrete quality C30/37. Use the same concrete factors as for static applications.

HST-Anchors



HST

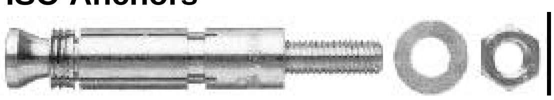


HST-R

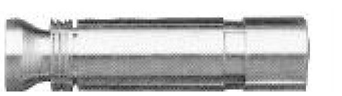
Anchor		Permitted Shock Load	Anchor	Hole	Anchor Spacing	Tightening Torque
Size	Type Denomination	F kN	∅ mm	Depth mm	s mm	T Nm
M 8	HST/HST-R M 8	2.80	8	65	80	25
M 10	HST/HST-R M10	5.10	10	80	100	45
M 12	HST/HST-R M12	6.80	12	95	120	60
M 16	HST/HST-R M16	11.30	16	115	160	125
M 20	HST/HST-R M20	16.90	20	140	200	240
M 24	HST/HST-R M24	22.60	24	170	250	300

Shock Approval: BZS D 97-232

HSC-Anchors



HSC-A/AR

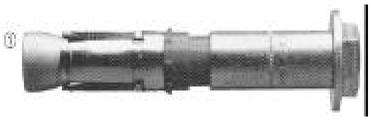


HSC-I/IR

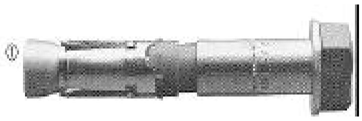
Anchor		Permitted Shock Load	Anchor	Hole	Anchor Spacing	Tightening Torque
Size	Type Denomination	F kN	∅ mm	Depth mm	s mm	T Nm
M 6	M 6x40 I/IR	4.50	14	46	80	8.5
M 8	M 8x40 A/AR	4.50	14	46	80	20
	M 8x40 I/IR	4.50	16	46	80	15
	M 8x50 A/AR	7.50	14	56	100	20
M 10	M10x40 A/AR	4.50	16	46	80	40
	M10x50 I/IR	7.50	18	58	100	30
	M10x60 I/IR	10.50	18	68	120	30
M 12	M12x60 A/AR	10.50	18	68	120	70
	M12x60 I/IR	10.50	20	68	120	60

Shock Approval: BZS D 95-258

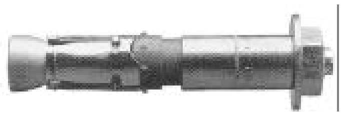
HSL-Anchors



HSL-TZ



HSL-B-TZ

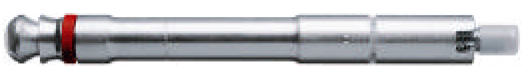


HSL-G-TZ

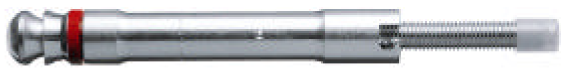
Anchor		Permitted Shock Load	Anchor	Hole	Anchor Spacing	Tightening Torque
Size	Type Denomination	F kN	∅ mm	Depth mm	s mm	T Nm
M 8	HSL/-TZ/-G-TZ	3.75	12	80	110	25
M 10	HSL/-TZ/-G-TZ	5.25	15	90	120	50
M 12	HSL/-TZ/-B-TZ/-G-TZ	9.00	18	105	160	80
M 16	HSL/-TZ/-B-TZ/-G-TZ	13.50	24	125	210	120
M 20	HSL/-TZ/-B-TZ/-G-TZ	19.50	28	160	260	200

Shock Approval: BZS D 96-203

HDA-Anchors



HDA-T



HDA-P

Anchor		Permitted Shock Load	Anchor	Hole	Anchor Spacing	Tightening Torque
Size	Type Denomination	F kN	∅ mm	Depth mm	s mm	T Nm
M 10	HDA-T M10 HDA-P M10	16.9	20	107	200	50
M 12	HDA-T M12 HDA-P M12	23.7	22	135	250	80
M 16	HDA-T M16 HDA-P M16	50.8	30	203	380	120

Shock Approval: BZS D 99-212

PI Shock

HVZ-Anchor
First chemical anchor with BZS-approval

Anchor		Permitted Shock Load	Anchor	Hole	Anchor Spacing	Tightening Torque
Size	Type Denomination	F kN	∅ mm	Depth mm	s mm	T Nm
M 10	HVZ M10x75	8.5	10	90	60	40 (SS 50)
M 12	HVZ M12x95	17.3	12	110	75	50 (SS 70)
M16	HVZ M16x105	21.9	16	125	85	90 (SS 100)
M 16	HVZ M16x125	27.3	16	145	85	90 (SS100)
M 20*	HVZ M20x170	51.9	25	190	135	150

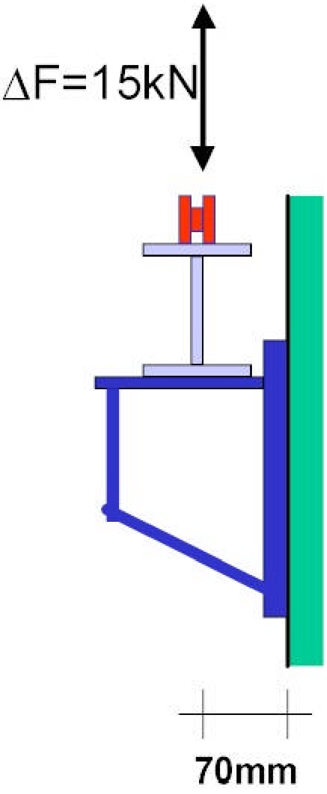
Shock Approval: BZS D 99-252

7. Examples Fatigue

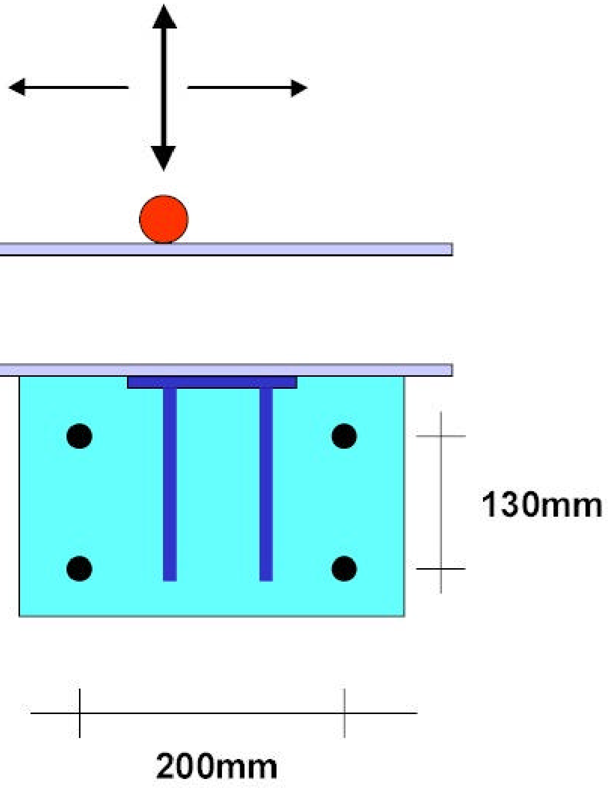
7.1 Simplified design for the fixing of crane track with dynamic loads in a concrete member

Given:	Hilti design anchor HDA-T M12,	
	anchoring in cracked concrete,	
	concrete strength class:	C25/30
	applied shear load:	$V_{S,k}$ = 15 kN (max. load)
	thickness of concrete member:	h > 250 mm
	spacing:	s1= 200mm
		s2= 130 mm
	length of anchor plate:	ℓ_x = 300 mm
	width of anchor plate:	ℓ_y = 230 mm
	number of load cycle	n = 2'000'000

Cross Section:



View:



7.1.1. Static check

load safety factor γ_Q=1.5

$V_{yd} = 15.0 \cdot 1.5 = 22.5kN,\ M_{xd} = 22.5kN \cdot 0.07m = 1.6kNm$

HIDU 3.0 results for HDA-T M12:

Tension:

steel failure: $\frac{N_{Sd}}{N_{Rd,s}} = 0.10$

Pullout failure: $\frac{N_{Sd}}{N_{Rd,p}} = 0.24$

Concrete cone failure: $\frac{N_{Sd}}{N_{Rd,c}} = 0.20$

Splitting failure: $\frac{N_{Sd}}{N_{Rd,sp}} = 0.20$

Shear:

steel failure: $\frac{V_{Sd}}{V_{Rd,s}} = 0.11$

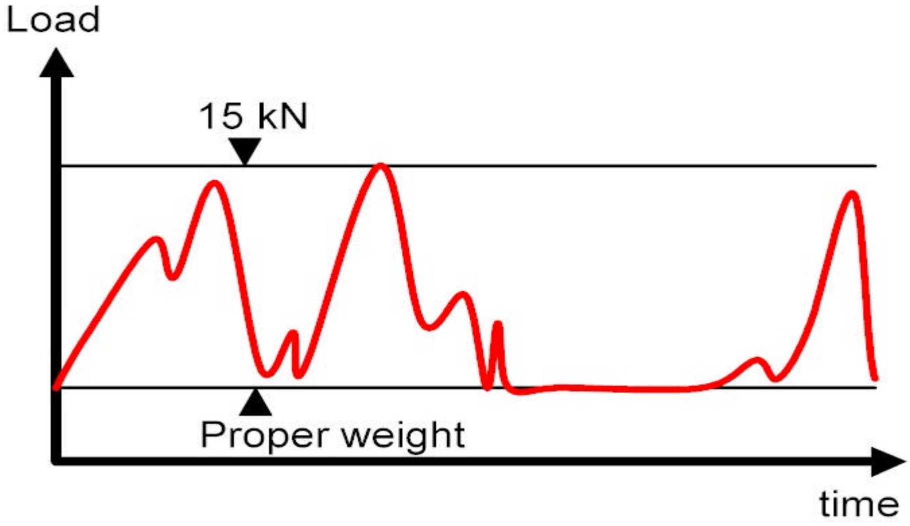
Pryout failure: $\frac{V_{Sd}}{V_{Rd,cp}} = 0.33$

combined load: 0.24 – 0.47

7.1.2. Simplified fatigue check

Assumptions:

- all loads fatigue relevant
- no prestressing force in anchor
- stiff baseplate
- $\gamma_{f,N} = \gamma_{f,V} = 1.0$ (load safety factor for single anchor)
- $\gamma_{f,N} = 1.3$ (group factor for tensile load, preliminary data)
- $\gamma_{f,V} = 1.2$ (group factor for shear load, preliminary data)



7.1.2.1 Acting Loads

single anchors

tensile load on upper single anchor in upper row = highest loaded anchor (out of statical calculation):

$$\Delta N^{h}_{Sd} = g_{f,N} \frac{N^{h}_{Sd}}{g_{Q}} = 1.3 \cdot \frac{4.6kN}{1.5} = 4.0kN$$

tensile load on lower anchor row:

$$\Delta N^{l}_{Sd} = g_{f,N} \frac{N^{l}_{Sd}}{g_{Q}} = 1.3 \cdot \frac{0.5kN}{1.5} = 0.4kN$$

Total tensile load anchor group for concrete cone check (without $\gamma_{F,N}$)

$$\Delta N^{g}_{Sd} = 2 \cdot \frac{N^{h}_{Sd}}{g_{f,N}} + 2 \cdot \frac{N^{l}_{Sd}}{g_{f,N}} = 2 \cdot \frac{4.0kN}{1.3} + 2 \cdot \frac{0.4kN}{1.3} = 6.8kN$$

shear load on single anchor:

$$\Delta V_{Sd} = g_{f,V} \frac{V_{Sd}}{n \cdot g_{Q}} = 1.2 \cdot \frac{22.5kN}{4 \cdot 1.5} = 4.5kN$$

with n: number of anchors in anchor group

7.1.2.2 Resistance

7.1.2.2.1 Tension

Steel failure (check only with highest loaded anchor):

tensile steel resistance single anchor

$$\Delta N_{Rd,s} = 11.8kN$$

Check single anchor:

$$\frac{\Delta N^{h}_{Sd}}{\Delta N_{Rd,s}} = \frac{4.0kN}{11.8kN} = 0.34 \quad \text{ok}$$

Concrete cone failure (check only with anchor group):

statical group resistance:

$$N^{g}_{Rk,c} = N^{0}_{Rk,c} \cdot \frac{A_{c,N}}{A^{0}_{c,N}} \cdot y_{s,N} \cdot y_{ec,N} \cdot y_{ucr,N}$$

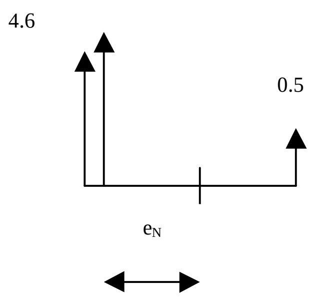
$$N^{0}_{Rk,c} = 8.3 \cdot \sqrt{f_{c,cube}} \cdot h_{ef}^{1.5} = 8.3 \cdot \sqrt{30} \cdot 120^{1.5} = 59.7kN \quad \text{(single undercut anchor)}$$

$$A^{0}_{c,N} = \left(s_{cr,N}\right)^2 = (375)^2 = 140'625\,mm^2$$

$$A_{c,N} = (1.5 \cdot 120mm + 130mm + 1.5 \cdot 120mm) \cdot (1.5 \cdot 120mm + 200mm + 1.5 \cdot 120mm)$$

$$= 274'400\,mm^2$$

$$\frac{A_{c,N}}{A^{0}_{c,N}} = 1.95$$



$\psi_{s,N}$=1.0 (no edge)

eccentricity due to bending moment:

$$e_N = \left(\frac{4.6kN \cdot 65mm - 0.5kN \cdot 65mm}{5.1kN}\right) = 52mm$$

$$\Psi_{ec,N} = \frac{1}{1 + 2e_N / s_{cr,N}} \leq 1$$

$$y_{ec,N} = 0.78$$

$$y_{ucr,N} = 1.0$$

$$N^{g}_{Rk,c} = 90.8kN$$

$$\Delta N^{g}_{Rk,c} = N^{g}_{Rk,c} \cdot 64\% = 58.1kN$$

(i.e. final resistance of concrete=64% statical resistance, acc. DIBt)

$$\Delta N_{Rd,c} = \frac{\Delta N_{Rk,c}}{g_{Mc}} = \frac{58.1kN}{1.62} = 35.8kN \quad (\gamma_{Mc}\text{ acc. DIBt})$$

check anchor group:

$$\frac{\Delta N_{Sd,c}}{\Delta N_{Rd,c}} = \frac{6.8kN}{35.8kN} = 0.19$$

Pullout failure (check only with highest loaded anchor):

$$\Delta N_{Rd,p} = f_B \cdot \Delta N^0_{Rd,p} = 1.1 \cdot 13.8kN = 15.2kN$$

with f_B:factor for influence of concrete strength for C25/30

Check single anchor:

$$\frac{\Delta N^h_{Sd}}{\Delta N_{Rd,p}} = \frac{4.0kN}{15.2kN} = 0.26 \quad \text{ok}$$

7.1.2.2.2 Shear

Steel failure:

shear resistance single anchor

$\Delta V_{Rd,s} = 11.3kN$ shear resistance of single anchor

check single anchor

$$\frac{\Delta V^h_{Sd}}{\Delta V_{Rd,s}} = \frac{4.5kN}{11.3kN} = 0.40 \quad \text{ok}$$

Concrete failure:

not decisive (no edges)

7.1.2.2.3 Interaction

Steel failure single anchor:

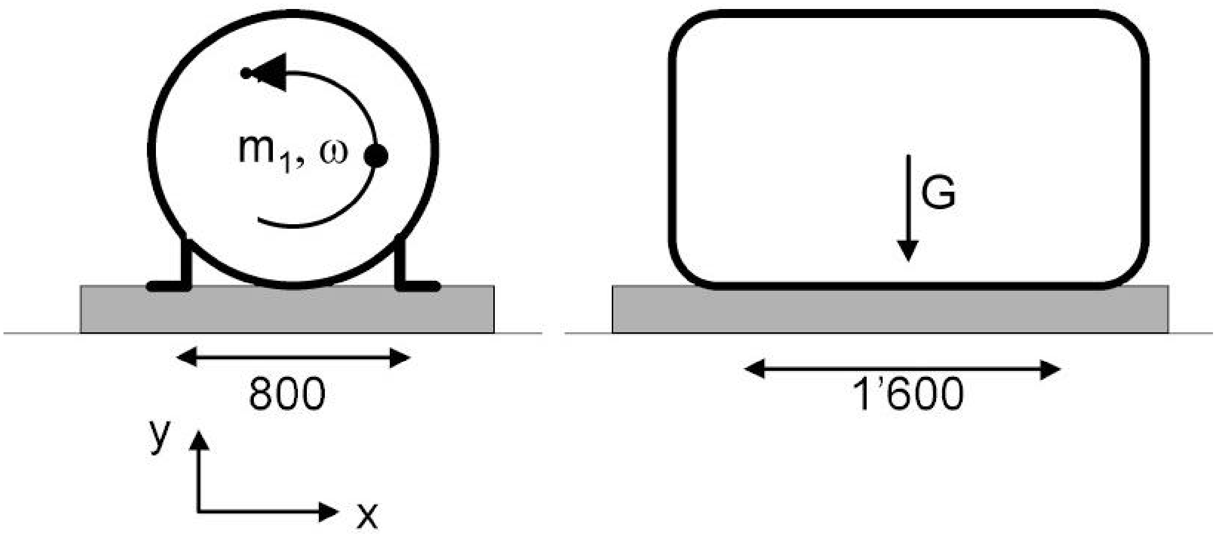
$$\frac{\Delta N^h_{Sd}}{\Delta N_{Rd,s}} + \frac{\Delta V^h_{Sd}}{\Delta V_{Rd,s}} = \frac{4.0kN}{11.8kN} + \frac{4.5kN}{11.4kN} = 0.74 \quad \text{ok}$$

7.2 Simplified design for the fixing of unbalanced rotating machine in a concrete member

Given: Hilti undercut anchor HDA

anchoring in cracked concrete,

concrete strength class:	C30/37
proper weight of machine:	m = 400 kg (max. load)
unbalanced mass:	m_1 = 5.0kg
radius of unbalance:	r_1 = 0.5m
rotation speed:	ω = 3'000 r/min
thickness of concrete member:	h > 250 mm
spacing:	s1= 800mm
	s2= 1'600 mm
length of anchor plate:	ℓ_x = 1'000 mm
width of anchor plate:	ℓ_y = 2'000 mm
number of load cycle	n = 2'000'000

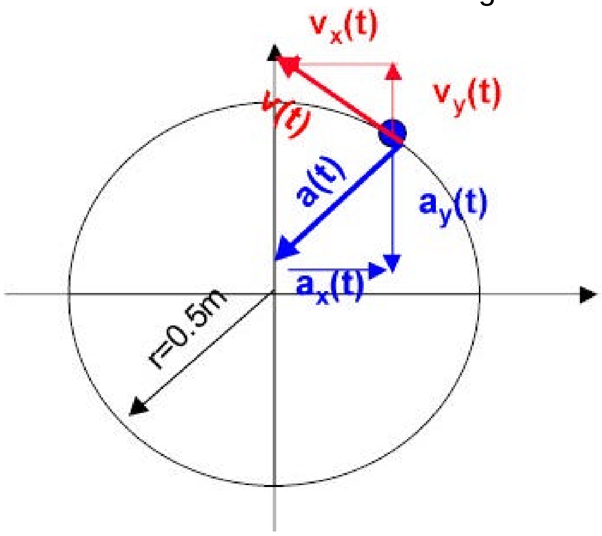


7.2.1 External loads

7.2.1.1 proper weight

$$G = m \cdot g = 400kg \cdot 9.81\frac{m}{s^2} = 3.9kN$$

7.2.1.2 external loads due to rotating unbalanced mass



lateral:

$$a_x(t) = -v^2 \cdot r_1 \cdot \cos a$$

$$v_x(t) = a_x(t)' = v^2 \cdot r_1 \cdot \sin a$$

$$F_{x,dyn}(t) = m_1 \cdot a_x(t) = -m_1 \cdot v^2 \cdot r_1 \cdot \cos a$$

$$F_{x,dyn,\max} = -F_{x,dyn,\min} = 5.0kg \cdot \left(50\frac{1}{s}\right)^2 \cdot 0.5m = 6.25kN$$

vertical:

$$a_y(t) = -v^2 \cdot r_1 \cdot \sin a$$

$$v_y(t) = a_y(t)' = -v^2 \cdot r_1 \cdot \cos a$$

$$F_{y,dyn}(t) = m_1 \cdot a_y(t) = -m_1 \cdot v^2 \cdot r_1 \cdot \sin a$$

$$F_{y,dyn,\max} = -F_{y,dyn,\min} = 5kg \cdot \left(50\frac{1}{s}\right)^2 \cdot 0.5m = 6.25kN$$

7.2.2 Static Check

maximum vertical load:
$$N_d^g = \gamma_G \cdot G + \gamma_Q \cdot F_{y,dyn} = 1.35 \cdot (-3.9kN) + 1.5 \cdot 6.25kN = 4.1kN$$
Tensile load on single anchor:
$$N_d = \frac{N_d^g}{4} = 1.02kN$$

maximum lateral load: $V_d^g = \gamma_Q \cdot F_{x,dyn} = 1.5 \cdot 6.25kN = 9.4kN$
Shear load on single anchor:
$$V_d = \frac{V_d^g}{n} = \frac{9.4kN}{4} = 2.35kN$$ with n: number of anchors

suitable anchors: HDA-P and HDA-T M10
HVZ M10
HST M10
HSL-TZ M10
HSC-A M12x60
HSC-I M10x60

7.2.3 Simplified Fatigue Check

Assumptions:

- all loads fatigue relevant
- no prestressing force in anchor
- stiff baseplate
- $\gamma_{f,N} = \gamma_{f,V} = 1.0$ (load safety factor for single anchor)

7.2.3.1 Acting Loads

single anchors

$$\Delta N_{Sd}^h = \gamma_{f,N} \cdot \frac{G + F_{y,dyn,max}}{n} = 1.0 \cdot \frac{-3.9kN + 6.25kN}{4} = 0.6kN$$

$$\Delta V_{Sd}^h = \gamma_{f,v} \cdot \frac{(F_{x,dyn,max} + |F_{x,dyn,min}|)}{n} = 1.0 \cdot \frac{(6.25kN + 6.25kN)}{4} = 3.1kN$$

7.2.3.2 Resistances

7.2.3.2.1 Tension

Steel Failure

tensile steel resistance single anchor HDA-T M10

$\Delta N_{Rd,s}$=6.7kN

check single anchor

$$\frac{\Delta N_{Sd}^{h}}{\Delta N_{Rd,s}} = \frac{0.6kN}{6.7kN} = 0.09 \text{ ok}$$

Concrete cone failure

statical resistance of single anchor

$$N_{Rk,c}^{0} = 8.3 \cdot \sqrt{f_{c,cube}} \cdot h_{ef}^{1.5} = 8.3 \cdot \sqrt{37} \cdot 100^{1.5} = 50.5kN$$

(single undercut anchor in C30/37)

$$\Delta N_{Rk,c} = N_{Rk,c} \cdot 64\% = 32.2kN$$

i.e. final concrete strength is 64% of statical concrete strength

$$\Delta N_{Rd,c} = \frac{\Delta N_{Rk,c}}{g_{Mc}} = \frac{32.2kN}{1.62} = 19.9kN$$

check single anchor

$$\frac{\Delta N_{Sd}}{\Delta N_{Rd,c}} = \frac{0.6kN}{19.9kN} = 0.03 \text{ ok}$$

Pullout failure

$$\Delta N_{Rd,p} = f_{B} \cdot \Delta N_{Rd,p}^{0} = 1.22 \cdot 9.9kN = 12.1kN$$

check single anchor

$$\frac{\Delta N_{Sd}}{\Delta N_{Rd,p}} = \frac{0.6kN}{12.1kN} = 0.05$$

7.2.3.2.2 Shear

Steel failure

shear resistance single anchor

$\Delta V_{Rd,s}$=6.3kN

check single anchor

$$\frac{\Delta V_{Sd}}{\Delta V_{Rd,s}} = \frac{3.1kN}{6.3kN} = 0.49$$

7.2.3.2.3 Interaction

Steel failure single anchor

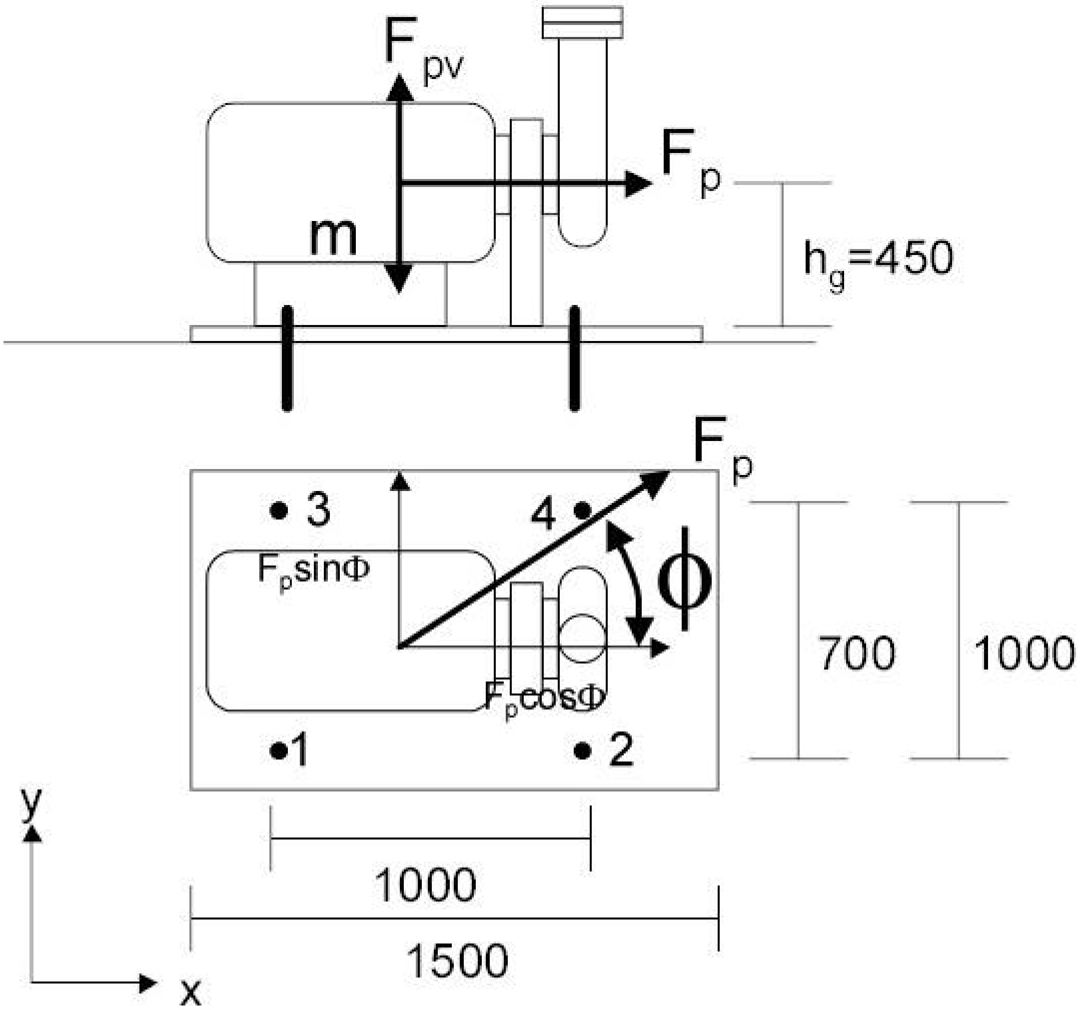
$$\frac{\Delta N_{Sd}^{h}}{\Delta N_{Rd,s}} + \frac{\Delta V_{Sd}^{h}}{\Delta V_{Rd,s}} = 0.58 \le 1.0 \text{ ok}$$

8. Examples Seismic Design

8.1 Rigidly floor mounted pump

Given: Baseplate with 4 Hilti anchors
anchoring in uncracked concrete,

concrete strength class:	C25/30 (≅4000psi)
applied mass:	m = 700 kg
thickness of concrete member:	h > 400 mm
spacing:	s_1= 1000mm
	s_2= 700mm
length of anchor plate:	ℓ_x = 1500 mm
width of anchor plate:	ℓ_y = 1000 mm
clearance hole in baseplate:	d=11mm ($^7/_{16}$")



Horizontal force caused by Earthquake;

$F_p = m \cdot G$

where m is the systems mass and G is the seismic factor according to local regulations

($F_{pv} = \frac{1}{3} \cdot F_p$ if necessary according to local codes)

assumption: G=0.5g

$F_p = m \cdot 0.5g = 700kg \cdot 0.5 \cdot 9.81 = 3.4kN$

$F_{pv} = \frac{1}{3} F_p = 1.15kN$

1. Tension

1.1 Overturning in direction F_p acc. to sketch

$$\Phi = \tan^{-1}\frac{n_1 \cdot s_1}{n_2 \cdot s_2} = \tan^{-1}\frac{2 \cdot 1000}{2 \cdot 700} = 55°$$

$$T_1 = \frac{(-m \cdot g + F_{pv})}{n_1 + n_2} + F_p \cdot h_g \left(\frac{\cos\Phi}{n_1 \cdot s_1} + \frac{\sin\Phi}{n_2 \cdot s_2}\right) =$$

$$\frac{-700kg \cdot 9.81\frac{m}{s^2} + 1'150N}{4} + 3'400N \cdot 0.45m\left(\frac{\cos 55°}{2 \cdot 1m} + \frac{\sin 55°}{2 \cdot 0.7m}\right) = -95N$$

T_1: tensile force on critical anchor 1
n_1: number of anchors along the length
n_2: number of anchors along the width
s_1: anchor spacing along the length
s_2: anchor spacing along the width

ϕ: critical angle where maximum tension occurs $\Phi = \tan^{-1}\frac{n_1 \cdot s_1}{n_2 \cdot s_2}$

h_g: height of center of gravity

1.2 Overturning short axis

$$T_{1,2} = \frac{-m \cdot g + F_{pv}}{n_1 + n_2} + \frac{F_p \cdot h_c}{s_2 \cdot n_2} = \frac{-700kg \cdot 9.81\frac{m}{s^2} + 1'150N}{4} + \frac{3'400N \cdot 0.45m}{0.7m \cdot 2} = -336N$$

$T_{1,2}$: tensile force on critical anchor 1 or 2

since the tensile load in both overturning considerations is negative, there is no additional force in the anchor.

2. Shear

$$V = \frac{F_p}{n_1 + n_2}$$

V: shear force on one bolt

$$V = \frac{F_p}{n_1 + n_2} = \frac{3'400N}{4} = 850N$$

Shear resistance according to ICBO ER 4627 for HKB $^{3}/_{8}$" with $1^{5}/_{8}$" embedment depth in concrete wit a resistance of 4'000psi (133% of static resistance):

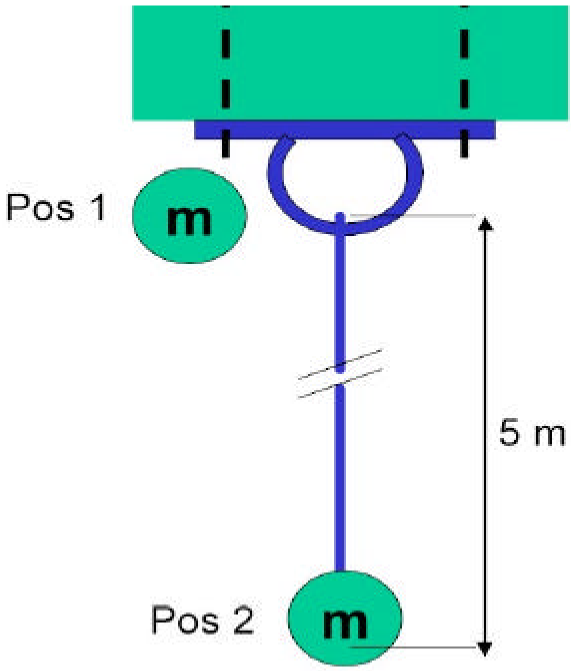
$$V_R = 1'075 lbs \cdot 0.453 \frac{kg}{lbs} \cdot 9.81 \frac{m}{s^2} * 133\% = 6.35 kN$$

9. Examples Shock

9.1 Inelastic Collision: Mass falling into a steel rope

Given:

Baseplate with 6 Hilti anchors	
anchoring in cracked concrete,	
concrete strength class:	C40/50
applied mass:	m = 30 kg
height of fall = length of rope:	L=5 meters
diameter of steel rope:	12 mm
steel elasticity:	210'000 N/mm^2
thickness of concrete member:	h > 400 mm
spacing:	s_1=s_2= 300mm
length of anchor plate:	ℓ_x = 800 mm
width of anchor plate:	ℓ_y = 500 mm



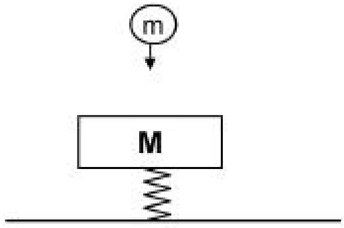
simplified assumption: static elasticity of rope = dynamic elasticity of rope
cross section of rope A_s=113 mm^2

spring elasticity $c = \frac{E \cdot A_s}{L} = \frac{210'000\, N/mm^2 \cdot 113\, mm^2}{5'000\, mm} = 4'750\, N/mm$

speed at end of fall $v_0 = \sqrt{2 \cdot g \cdot h} = 9{,}9\, m/s$

dynamic factor $l = \frac{d_{Dyn}}{d_{stat}} = 1 + \sqrt{1 + \frac{(m_1 + M)v_1^2 \cdot c}{m_1^2 \cdot g^2}}$ M: substitute mass, here =0

Examples Shock



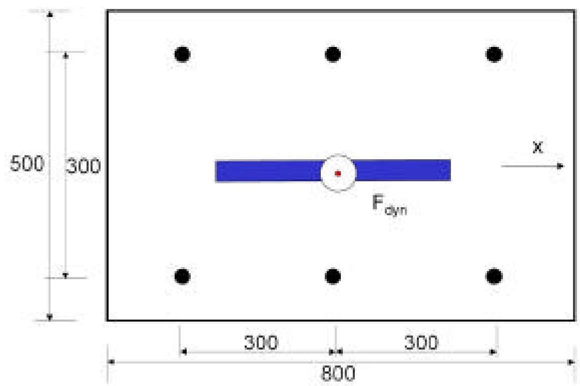
$$l = 1 + \sqrt{1 + \frac{m \cdot v_0^2 \cdot c}{m^2 \cdot g^2}} = 402$$

static elongation $d_{stat} = \frac{m \cdot g}{c} = \frac{30\,kg \cdot 9.81 m/s^2}{4'750'000\,N/m} = 0.062\,mm$

dynamic elongation $d_{dyn} = l \cdot d_{stat} = 402 \cdot 0.062\,mm = 25 mm \Rightarrow e = \frac{d_{dyn}}{L} = 0.50\%$

=> elastic

dynamic Force: $F_{dyn} = s \cdot A_s = E \cdot e \cdot A = 210\,kN/mm^2 \cdot 0.0050 \cdot 113 mm^2 = 118 kN$



1st Approach:
only elastic deformations admissible: => design with static approach
use only anchors suitable for cracked concrete
Acting Forces:
Nd=γ_G*F_{dyn}= 1.35*118kN=159.3kN
suitable anchors (out of HIDU statical calculation)
HDA-P M16, HDA-T M16, HVZ M20

2nd Approach:
plastic deformations admissible: => compare acting loads to shock resistance (BZS approval) acting load on single anchor: 19.7 kN
valid anchors:
HST M24: 19.7kN/22.6kN=0.87
HDA M12: 19.7kN/23.7kN=0.83
HVZ M16x105: 19.7kN/21.9kN=0.90

9.2 Simplified Design acc. to Regulations of BZS*

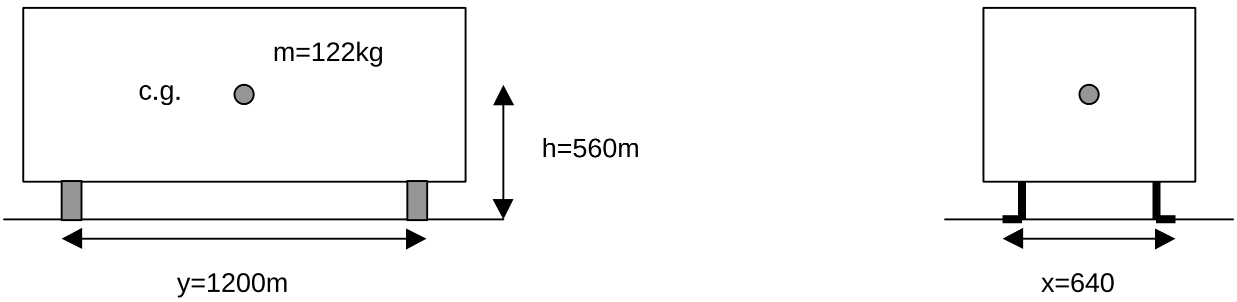
*BZS: Bundesamt für Zivilschutz (Swiss Federal Authority for Civil Defence)

Assumptions:
The shock loads are substituted by static forces with

$$F = DLF \cdot m \cdot a_{max}$$

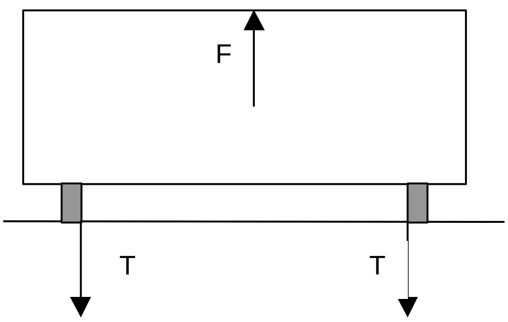
F: static Force
DLF: dynamic load factor (recommendation F=1.25)
m: mass of equipment
a_{max}: maximum acceleration (recommendation a_{max}=125 m/s^2)

F acts additionally to all other forces in the centre of gravity in the most critical direction. This means the shock design has to be done in the direction of three orthogonal axis.



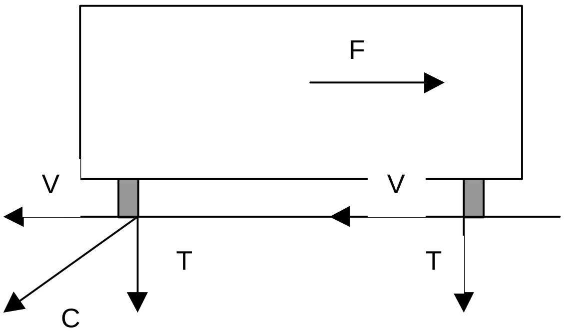
$$F = 1.25 \cdot 122kg \cdot 125\frac{m}{s^2} = 19'063N$$

a) vertical action



$$T = \frac{F}{4} = 4'760N$$

b) longitudinal horizontal action

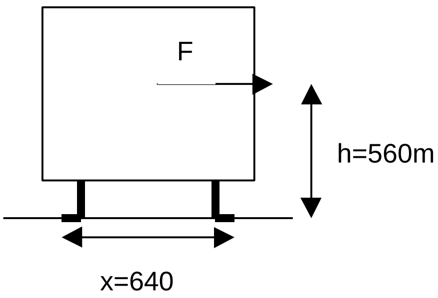


assumption: $V = \frac{F}{4} = 4'760N$

$$T = \frac{F \cdot h}{2 \cdot y} = \frac{19'036N \cdot 560mm}{2 \cdot 1'200mm} = 4'450N$$

$$C = \sqrt{V^2 + T^2} = \sqrt{4'760^2 + 4'450^2} = 6'520N$$

c) lateral horizontal action



assumption: $V = \frac{F}{4} = 4'760N$

$$T = \frac{F \cdot h}{2 \cdot x} = \frac{19'036N \cdot 560mm}{2 \cdot 640mm} = 8'340N$$

$$C = \sqrt{V^2 + T^2} = \sqrt{4'760^2 + 8'340^2} = 9'600N$$

Maximum Load a) – c): 9’600N for a single anchor

Suitable Hilti Anchors:	adm. shock Load acc. BZS Approval
HST M16	11.3 kN
HSC(-I) M10x60 or HSC (-I) M12x60	10.5 kN
HSL-TZ, HSL-B-TZ, HSL-G-TZ M16	13.5 kN
HDA-P, HDA-T M10	16.9 kN
HVZ M12	17.3 kN

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DIBt-Zulassungen	
ET Approvals	
BZS Approvals	
ICBO Approvals	

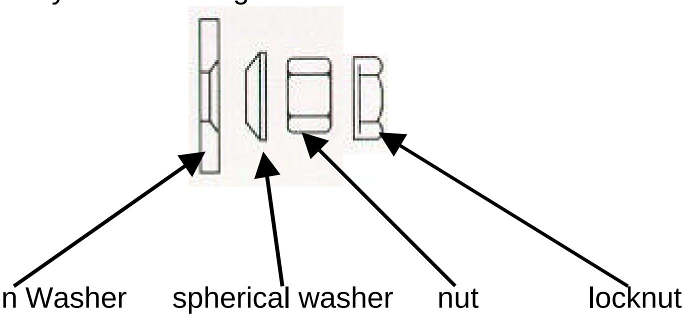
Appendix A: Dynamic Set

General

For all dynamic actions three main challenges can be identified:
1. For an easy installation the clearance hole always is larger than the external diameter of the anchor. For static loads this is of negligible relevance, but for dynamic loads any relative movement between baseplate and anchor can have a negative impact.
2. As most of the anchors are drilled manually they are never 100% vertical. This leads also with pure tensile loads to bending moments in the anchor.
3. With dynamic loads even properly installed anchors have sometimes the problem, that the nuts start to loosen during lifetime.

Dynamic Set

To improve this situation Hilti has developed the so called "Dynamic Set". This includes a special injection washer to fill up the clearance hole with HIT-HY150, a spherical washer to avoid the bending in the anchor, a standard nut and a special locknut to avoid any nut loosening.



This dynamic set has to be used for all fatigue applications and the load values given in the "PI fatigue" in chapter 4 are only valid in combination with this set. For all other applications the use of this set is not mandatory but it helps to improve the situation especially if shear forces are acting.

Setting instructions
(e.g. HDA)