

Dynamic loads (seismic, fatigue, shock)

Dynamic design for anchors

Detailed informations are available from your local Hilti partner or in the brochures:
 Hilti engineering for earthquake applications, Hilti AG, 2011
 Dynamic Design for Anchors, Hilti AG, 2001

Actions

Common engineering design usually focuses around static loads. This chapter is intended to point out those cases, where static simplification may cause severe misjudgement and usually under-design of important structures.

Static loads

Static loads can be segregated as follows:

- Own (dead) weight
- Permanent actions
- Loads of non-loadbearing components
- Changing actions
- working loads (fitting / furnishing , machines, "normal" wear)
- Snow, Wind, Temperature

Material behaviour under static loading

The material behaviour under static loads is described essentially by the strength (tensile and compressive) and the elastic-plastic behaviour of the material. These properties are generally determined by carrying out simple tests with specimens.

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.

Typical Dynamic Actions

Dynamic actions can generally be classified into 3 different groups:

- Seismic loads
- Fatigue loads
- Shock loads

Seismic loads

Earthquakes



An increasing population density, the concentration of valuable assets in urban centers and society's dependence on a functioning infrastructure demand a better understanding of the risks posed by earthquakes. In several areas around the globe, these risks have been reduced through appropriate building codes and state of the art construction practices. The development of pre-qualification methods to evaluate building products for seismic conditions additionally contributes to safer buildings for generations to come.

Anchors suitability under seismic loading

For a properly designed fastening, anchors subjected to seismic loading shall be designed and additionally pre-qualified for seismic load scenarios. In view of this, suitability tests for tension and shear are carried out according to ACI 355.2 with the ICC acceptance criteria AC193 and AC308. As a consequence of this procedure, for the suitable anchors, technical data is published and an evaluation technical report (ESR) is released.

Additionally, Hilti's seismic research includes detailed investigation of product performance under simulated seismic conditions and full-scale system testing. This multilevel approach helps to capture the complexity of anchored system behaviour under seismic conditions.

Seismic anchorage applications can include strengthening or retrofitting an existing structure, as well as standard anchorage applications that exist both in seismic and non-seismic geographies. In addition to an engineers focus on the anchoring of structural elements, it is crucial for an adequate seismic design to attend to non-load bearing and non-structural elements. These elements failure can severely compromise the building/structure functionality or repair costs after a seismic event.

For a sound seismic design of a post-installed anchorage the first step begins with the correct definition of the acting loads. In the United States ASCE/SEI 7-05 establishes the provisions for the definition of the seismic action, and the anchor performance shall be evaluated in accordance with ACI 318-08, Appendix D. Pre-qualification reports, created in accordance with published testing procedures and acceptance criteria, (ACI 355.2 with ICC-ES AC193 and AC308) provide sound data in a proper format for design.

Following the same design flow, in Europe the action definition is available through the EN 1998:2004 (Eurocode 8) and the resistance evaluation can be defined by the CEN/TS 1992-4:2009. However, the anchor's seismic pre-qualification testing description is still under development. As such, the European framework is not yet harmonized in order to allow the design of a post-installed anchorage under seismic conditions.

Under seismic loading the performance of an anchored connection is crucial either to the stability of a structure or in order to avoid major casualties and/or economical impacts consequence of non-structural elements collapse. Therefore, to consent in Europe the design of anchors subjected to seismic action, the resistance evaluation may utilize the provisions and technical reports existing in the United States.

By an in-depth analysis and comparison of the code regulations on both continents it is possible to establish a plain harmonization. A comparison of ASCE/SEI 7-05 and Eurocode 8 in terms of the design spectrum, seismic base shear force and also the load combinations concept to account for earthquake action allows for a sound recommendation of this approach.

The above mentioned design exercise is presently the only available and fully operational code based procedure in Europe and can as such be considered state-of-the-art. Upon the development of pre-qualification criteria and technical data for the seismic design of anchors in Europe, a designer will be recommended to reference to most recent published design approach.

After a strong or design earthquake occasion, the ultimate loading capacity of an anchor is considerably reduced (30 to 80% of the original resistance). Proper inspection shall then be carried to ensure the level of performance not only for a future earthquake but also to guaranty the load combinations for static loading.

Typical seismic applications

Seismic anchor design regulations landscape

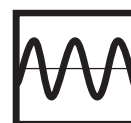
Engineering judgment on the design procedure

After an earthquake

Fatigue loads

If an anchor 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. When evaluating actions causing fatigue also the planned or anticipated fastening life expectancy is of major importance.

Fatigue



Material behaviour under fatigue impact

The grade and quality of steel has a considerable influence on the alternating strength. In the case of structural and heat-treatable steels, the final strength (i.e. after 2 million load cycles or more) is approx. 25-35% of the static strength.

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. Concrete strength is reduced to about 55 – 65% of the initial strength after 2'000'000 load cycles.

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 (e.g. ventilators, production machinery, etc.).
- Repeated loading and unloading of structures with high loads and frequent recurrence (cranes, elevators, robots, etc.).

Shock loads

Shock



Shock-like phenomena have a very short duration and generally tremendously high forces which, however, only occur as individual peaks. As the probability of such a phenomenon to occur during the life expectancy of the building components concerned is comparably small, plastic deformations of fasteners and structural members are permitted according to the pre-qualification criteria.

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, ship or aeroplane impacts and falling rocks, avalanches and explosions, etc.).

Shock Testing

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:

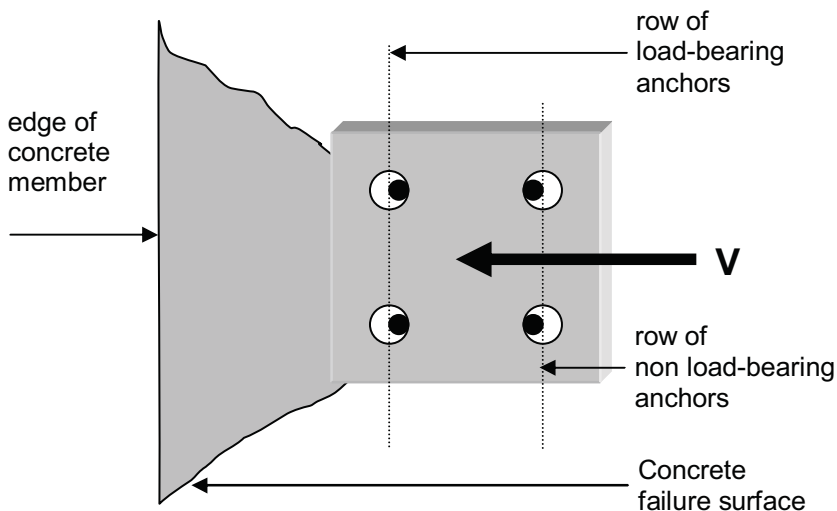
- Deformation is greater when the breaking load is reached
- The energy absorbed by an anchor is also much higher
- Breaking loads are of roughly the same magnitude during static loading and shock-loading tests

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

Dynamic set for shear resistance upgrade

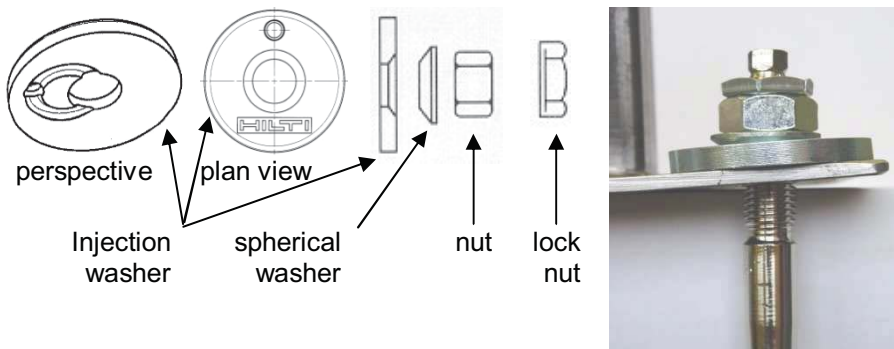
If a multiple-anchor fastening is loaded towards the edge of a concrete member (shear load), the gap between anchor shaft and clearance hole has an important role. An uneven shear load distribution within the anchors in the fastening is the result as the clearance hole is always larger than the anchor diameter to ensure an easy installation. Design methods take this fact into account by assuming that only the row of anchors nearest to the concrete edge takes up all shear load.

Uneven shear load distribution



The second row of anchors can be activated only after a considerable slip of the anchoring plate. This slip normally takes place after the edge failure of the outside row. The effect of the clearance hole gap on the internal load distribution increases if the shear load direction changes during the service life. To make anchors suitable for alternating shear loads, Hilti developed the so called Dynamic Set. This consists of a special washer, which permits HIT injection adhesive to be dispensed into the clearance hole, a spherical washer, a nut and a lock nut.

Activating the second row of anchors



Dynamic Set

Injection washer: Fills clearance hole and thus guarantees that the load is uniformly distributed among all anchors.

Spherical washer: Reduces bending moment acting on anchor shaft not set at right angles and thus increases the tensile loading capacity.

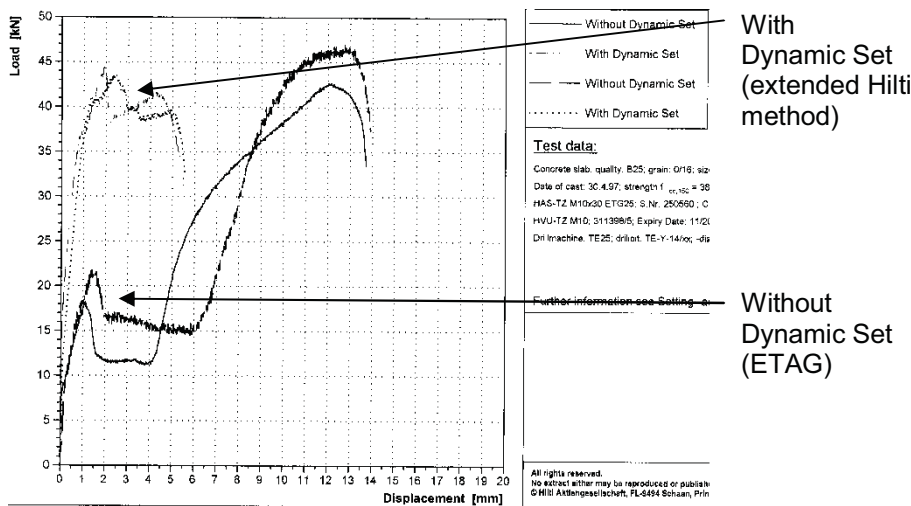
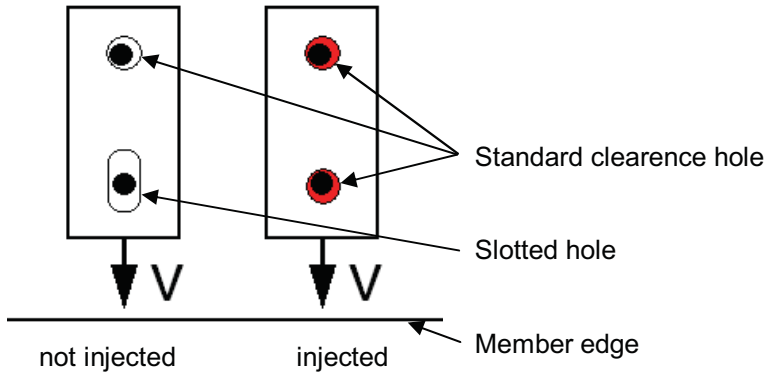
Lock nut: Prevents loosening of the nut and thus lifting of the anchoring plate away from the concrete in case of cyclic loading.

Improvements with Dynamic Set

Delivery programme Dynamic Set: M10, M12, M16, M20

Shear resistance improvement with Dynamic Set

By using the dynamic set for static fastenings, the shear resistance is improved significantly. The unfavourable situation that only one row of anchors takes up all loads no longer exists and the load is distributed uniformly among all anchors. A series of experiments has verified this assumption. An example from this test programme, double fastenings with HVZ M10 anchors with and without the Dynamic Set are shown to compare resulting shear resistance and stiffness.



TWU 07/01 Shear Load Capacity with and without Dynamic Set
 Monotonic shear-tension - HVZ M10 - HAS-TZM10x30
 Depth of embedment $h_{ef} = 80$ mm; Edge distance = 60 mm; 285 mm

The test results show clearly that according to the current practice the second row of anchors takes up the load only after significant deformation of the plate, when the concrete edge has already failed. The injection and the Dynamic Set resulted in a continuous load increase until the whole multiple fastening fails.

When carrying out a simple fastening design, it may be assumed if the Dynamic Set is used the overall load bearing capacity of the multiple fastening is equal to the resistance of the first row of anchors multiplied by the number of rows in the fastening. In addition to that it must be checked whether the concrete edge resistance of the farrest row is smaller than the above mentioned resistance. If injection with the Dynamic Set is used, the ETAG restrictions on more than 6 anchor fastenings can be overcome.