

6. Concrete base material

6.1 Anchoring mechanisms

The following three mechanisms cause a DX-/GX-fastener to hold in concrete:

- Bonding / sintering
- Keying
- Clamping

These mechanisms have been identified and studied by analyzing pull-out test data and by microscopic examination of pulled-out fasteners and the concrete to fastener interface.

Bonding / sintering

When driving a fastener into concrete, the concrete is compacted. The intense heat generated during driving causes concrete to be **sintered** onto the fastener. The strength of this sintered bond is actually greater than that of the **clamping** effect due to reactive forces of the concrete on the fastener.

The existence of the sintered bond is demonstrated by examining pulled-out fasteners. The fastener surface, especially in the region of the point, is rough due to sintered-on concrete, which can only be removed by using a grinding tool.

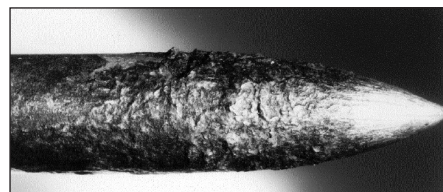
When performing pull-out tests, the most common failure mode is breakage of the sintered bond between the concrete and the fastener, especially at and near the point.



Keying

The sintered material forms ridges on the fastener surface. These ridges result in a micro-interlocking of the fastener and the concrete.

This anchoring mechanism is studied by examining pulled-out fasteners under a microscope. As in the case of sintering, keying is primarily active in the region of the fastener point.



Mechanically cleaned point of a pulled-out DX fastener

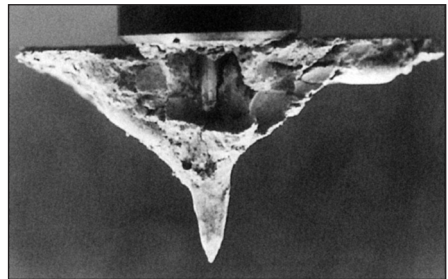
Clamping

The compressibility of concrete limits the buildup of compressive stress around the driven fastener. This in turn limits the effectiveness of clamping as an anchoring mechanism.

The tendency of stressed concrete to relax further reduces the compressive stress and hence the clamping effect. For these reasons, clamping of the fastener shank contributes only insignificantly to the total pull-out strength.

Concrete failure

Concrete cone failure is occasionally observed when using a testing device with widely spaced supports. The fact that the concrete failed indicates that the fastener bond to the concrete was stronger than the concrete.



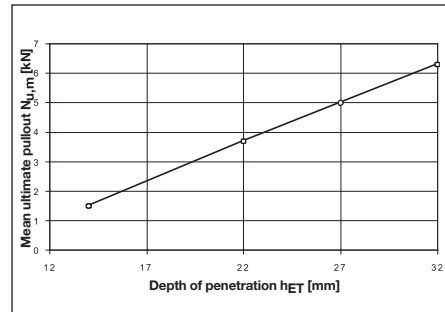
6.2 Factors influencing resistance to pull-out

Factors that can affect the pull-out strength of fastenings to concrete include:

- Depth of penetration into the concrete
- Concrete parameter (compressive strength, grain structure, direction of concrete placement)
- Distance to concrete edge and fastener spacing

Depth of penetration h_{ET}

Fasteners that are driven deeper typically have a higher resistance to pull-out. This relation is best shown by placing groups of fasteners with different driving energy and comparing the results for each group with the others. The result of such a test is shown in the graph at the right. Note that fastener driving failures were not considered in calculation of the average ultimate load, $N_{u,m}$.

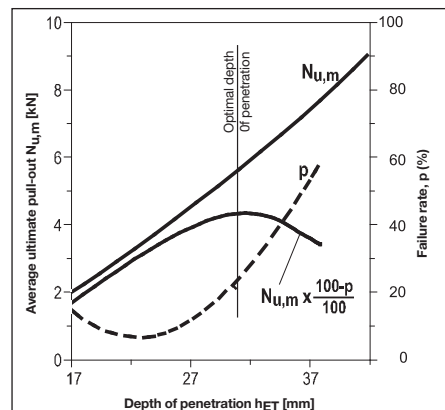


The value of increasing the depth of penetration in order to increase pull-out strength is limited by the increasing fastener driving failure rate. Provided that the penetration depth is the same, fastenings in concrete with a higher compressive strength hold better than fastenings in lower strength con-

crete. The ability to exploit this characteristic is also limited by increased fastener driving failure rate with higher strength concrete. As could be expected, the depth of penetration at which the failure rate is at a minimum decreases with increasing concrete strength.

Pull-out strength and fastener driving failure rate both increase with increasing penetration depth. The optimum depth of penetration is taken as the depth at which the yield in terms of pull-out strength begins to decrease. This is within a range of 18–32 mm depending on the grade and age of the concrete as well as the strength of the fastener.

$$\text{yield} = N_{u,m} \cdot \left(\frac{100 - p}{100} \right)$$



Concrete parameters

The concrete parameters (such as the type and size of concrete aggregates, type of cement and the location on top or bottom surface of a concrete floor) do affect the fastener driving failure rate, sometimes significantly.

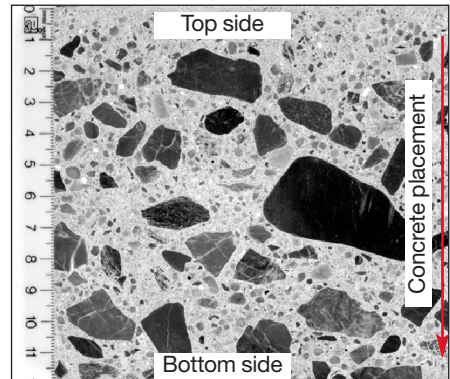
Fastener driving failures are caused by the fastener hitting a hard aggregate, such as granite, located close to the concrete surface. A hard aggregate can deflect the fastener and in a severe case, the fastener may bend excessively, leading to con-

crete fracture in a cone shape and no hold being obtained by the fastener.

In case of slight fastener bending, concrete spalling may occur at the surface. However, because pull-out strength is obtained mostly in the area of the fastener point, concrete spalling does not affect the permissible load of the DX-/GX-fastening.

Softer aggregates such as limestone, sandstone or marble may be completely penetrated when hit by the fastener.

Overhead fastening is usually associated with a higher rate of fastener driving failure than floor fastening. This is due to the distribution of the aggregates within the concrete. Large aggregates tend to accumulate at the bottom of a floor slab. At the top, there is a greater concentration of small aggregates and fines.

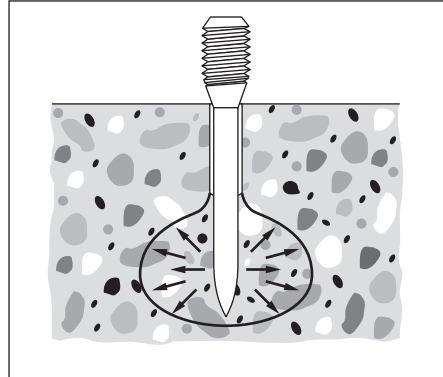


There are several possible ways of reducing the failure rate when powder-actuated fasteners are used for fastening to concrete. There are two basic ideas: one is to

reduce concrete tensile stresses near the surface and the other is to delay the effect of these stresses.

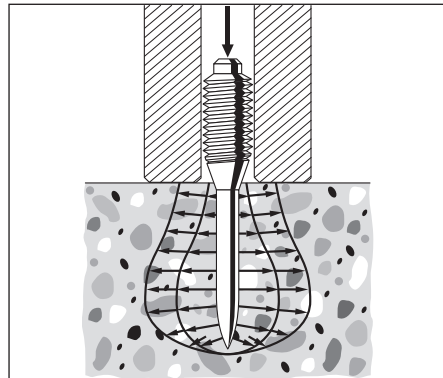
Pre-drilling the concrete (DX-Kwik)

By pre-drilling a very small hole (5mm diameter, 18 or 23 mm deep), the stresses are relocated to greater depth in the concrete. Fasteners placed with DX-Kwik are surrounded by a stress “bulb” located deep in the concrete. With this method, virtually no fastener driving failures occur.



Spall stop fastener guide

A spall stop is a heavy steel fastener guide. Its weight and inertia counteract the stresses at the surface for a very short time. This allows redistribution of the stresses to other parts of the concrete.



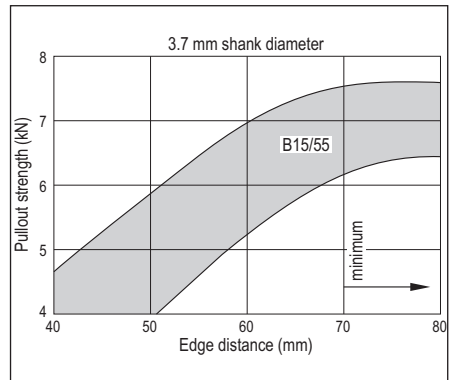
Changing from a long to a short fastener reduces the magnitude of the stresses and thus the rate of fastener driving failure.

Edge distance and fastener spacing

If fasteners are placed too close to the concrete edge, pull-out load capacity will be reduced. Minimum edge distances are therefore published with a view to reducing the effect edges have on pull-out strength. The corresponding data has been obtained from tests and analysis and is given in part 2 of this manual.

Additional provision is made for fastener spacing when positioned in pairs or where fasteners are placed in rows along a concrete edge.

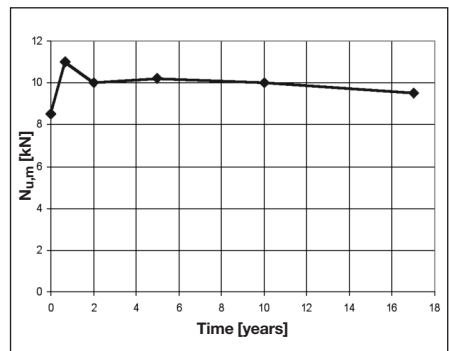
These edge distances and spacing also have the purpose of helping to prevent concrete spalling and/or cracking due to fastening. However, spalling has generally only an insignificant influence on pull-out strength.



6.3 Effect of time on pull-out resistance

The effect of age on pull-out strength has been investigated in comprehensive tests. The main concern is, in fact, the effect of concrete relaxation in the area around the driven fastener.

This graph provides an overview of tests performed with DX-Kwik fasteners. Since standard DX fastenings have the same anchoring mechanism, this statement is also valid for standard DX fastenings. The test results indicate very strongly that relaxation of the concrete has no detrimental effect on the pull-out resistance of DX fastenings. The test data also shows that sintering and keying are the dominant anchorage mechanisms because they do not rely on friction between the fastener and the concrete.



6.4 Effect on concrete components

Fastenings in the compression zone of the structure have no effect on concrete compressive resistance as long as detailed provisions on edge distance and spacing are complied with.

Fastenings in the **tensile zone** are subject to the following provisions:

- a. **Installations on plain load-bearing components such as concrete walls or ceilings are generally possible without restrictions** as the load-bearing behaviour of these components is only negligibly affected by the fasteners. The predominant condition is static loading. This statement is based on experimental investigations carried out at the Technical University of Braunschweig, Germany.
- b. Fastenings in reinforced concrete beams: it has to be ensured that the main rein-

forcement steel will not be hit or penetrated by the DX fasteners. This measure of precaution is mainly founded on the reduction of the ultimate strain of the steel reinforcement. Exceptions are possible when the structural engineer responsible for design is consulted.

- c. Fastenings in pre-stressed concrete members:

it has to be ensured that the pre-stressing steel reinforcement or cables will not be hit or penetrated by the DX fasteners.

If the concrete is too thin, concrete will spall off on the rear surface. The minimum thickness of concrete depends on the shank diameter of the fastener used.

Fastener shank diameter d_{nom} (mm)	Minimum concrete thickness h_{min} (mm)
3.0	60
3.5 / 3.7	80
4.5	100
5.2	100