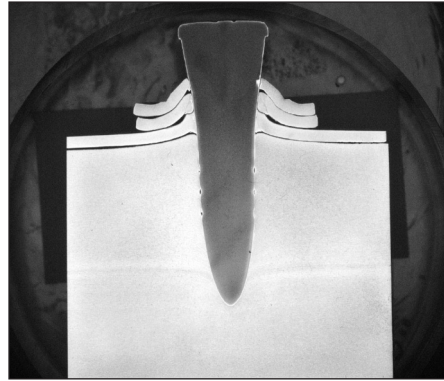# 5. Steel base material

5.1 Anchoring mechanisms

The following four mechanisms cause a
DX- / GX-fastener to hold when driven into
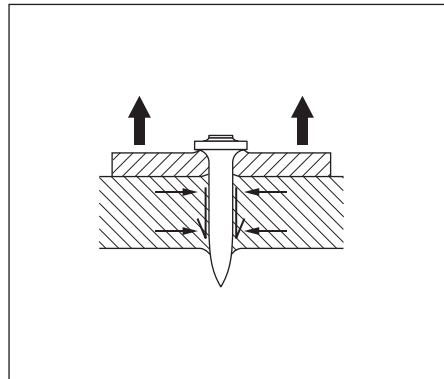steel:

• clamping

• keying

• fusing (welding)

• soldering

These mechanisms have been identified and
studied by analyzing pull-out test data and
by microscopic examination of fastening
cross-sections.

Clamping

As a fastener is driven, the steel is displaced
radially and towards both the entry and
opposite surfaces. This results in residual
pressure on the surface of the nail, which
leads to friction or clamping. Clamping is the
primary anchoring mechanism of through-
penetrating fasteners. This is indicated by
the fact that when through-penetrating fas-
teners are extracted, the pull-out force
decreases only slowly over several millime-
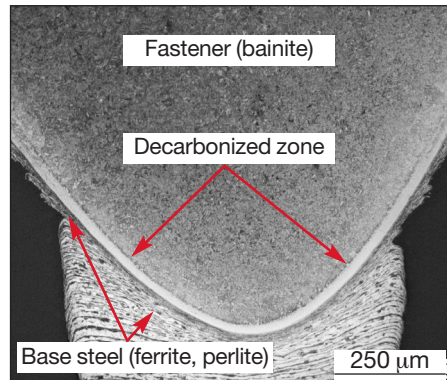ters of displacement.

Keying

The keying mechanism is possible when the
fastener is knurled, that is, it has fine
grooves along the shank in which zinc and
particles of base steel accumulate during
the driving process. Microscopic examina-
tion of cross sections has shown that the
grooves are not completely filled. Keying is
an especially important anchoring mecha-
nism for fasteners that do not penetrate right
through the base material.

Knurling

Base steel

Fastener

1 mm
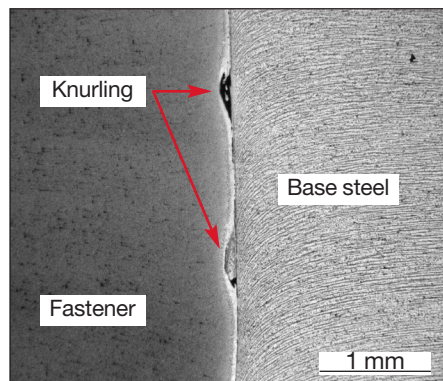
Fusing (welding)

Complete fusing of the fastener with the base steel is indicated by portions of base material clinging to the extracted fastener as well as by the decarbonized zone. Fusing or welding is observed mostly at the point of a fastener where the temperature during driving can be expected to be the highest.

For fasteners that do not through-penetrate, this is an important anchoring mechanism. It can be relied upon only if the fastener point is manufactured without cracks and with an appropriate geometry. The thermo pulling process is ideal for achieving an optimized geometry. Control of all steps in the production process is necessary to avoid cracks in the point.

Fastener (bainite)

Decarbonized zone

Base steel (ferrite, perlite)

250 μm

Soldering

In the zone further from the point, there is a prominent zinc layer separating the fastener from the base steel. This zinc, soldered to the base steel, also makes a contribution to the pull-out resistance of the fastener.

Fastener

Base steel

Zinc layer

250 μm
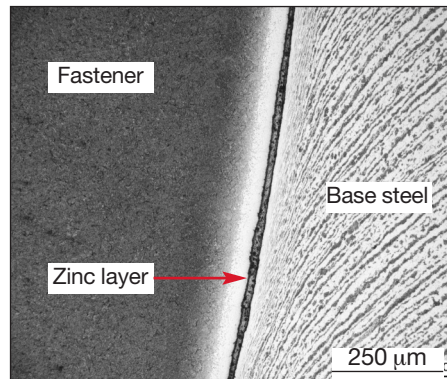
Blunt-tipped fastener X-BT

The X-BT fastener with a shank diameter of 4.5 mm is driven in a pre-drilled 4.0 mm diameter hole. This leads to displacement of the base material. Part of the base steel is punched down into the pre-drilled hole, generating high temperatures and causing friction welding. Due to elasticity of the base steel, additional clamping effects are also superposed. Displaced base material can be clearly seen in the photograph. Base material adhering to the fastener shank indicates a welding effect.

5.2 Factors influencing pull-out resistance

Powder-actuated fastening systems must be designed and manufactured to ensure that pull-out resistance will be adequate for the applications intended. Through understanding of the anchoring mechanisms, experience and testing, factors that influence pull-out strength have been identified. Some of these factors are:

• Depth of penetration in the base material
• Surface characteristics of the fastener
• Coatings on the steel base material
• Driving velocity
• Diameter of the fastener shank

Knowledge of the influencing factors is vital to the design of fastening systems and is useful for operators in understanding the various application guidelines and restrictions that apply to a fastening system. Some of the influencing factors are discussed in the following section.

Depth of penetration in the base material

The depth of penetration of fasteners in steel is taken as the distance that the point travels below the surface of the base steel, independent of the steel thickness. In other words the depth of penetration h_{ET} can be greater than, equal to or less than the steel thickness.
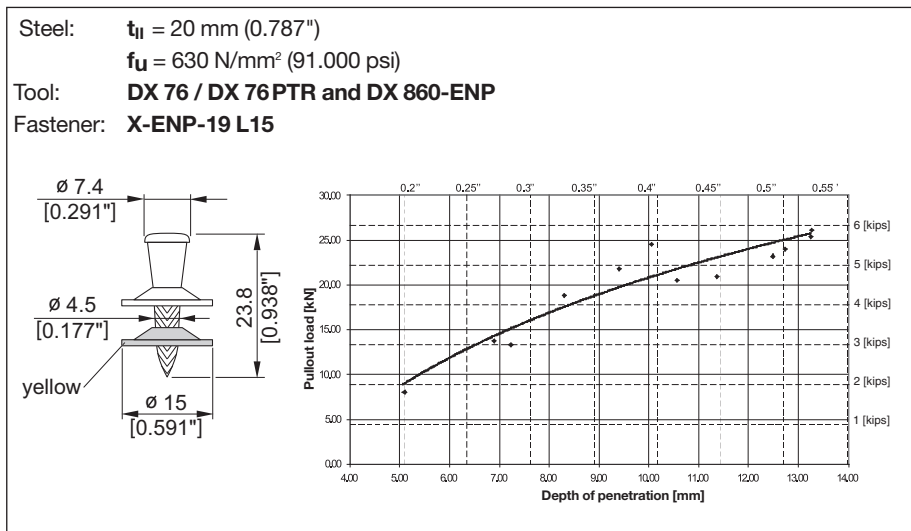
Resistance to pull-out increases with increasing depth of penetration. This is also true for through-penetrating fasteners where h_{ET} is greater than the steel thickness. The design of a powder-actuated fastener has to take into account the depth penetration necessary to achieve the pull-out resistance required for the application. Application guidelines published for any fastener include the required nail head stand off h_{NVS}, which corresponds to the penetration depth.

Siding and decking pin **X-ENP-19 L15**

Nail for X-HVB composite connector **X-ENP-21 HVB**
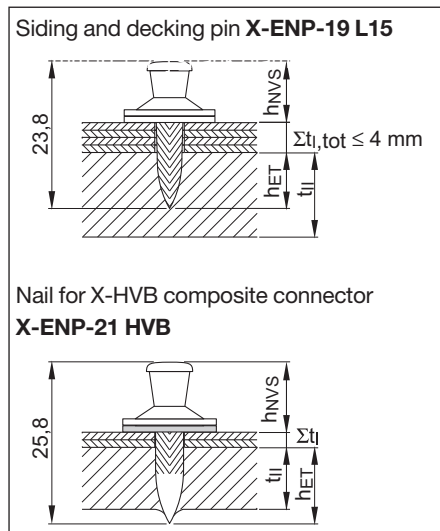
Guide values for the depth of penetration of specific fastener types are as follows:

|		
Galvanized fastener with knurled shank:	h_{ET} = 12 to 18 mm	(shank diameter 4.5 mm)
	h_{ET} = 10 to 14 mm	(shank diameter 3.7 mm)
Galvanized fastener with knurled tip:	h_{ET} = 9 to 13 mm	(shank diameter 4.5 mm)
Galvanized fastener with smooth shank:	h_{ET} = 15 to 25 mm	
Stainless steel fastener with smooth shank:	h_{ET} = 9 to 14 mm	
Blunt-ended fasteners:	h_{ET} = 4 to 5 mm	

The effect of penetration depth on pull-out strength can be demonstrated in experiments in which the driving energy is varied so as to produce varying penetration. The results of a test of this kind are summarized below. The application recommendations for fasteners are based on tests like these and they clearly show the importance of carrying out the fastening work in accordance with the recommendations of the manufacturer.

Steel: t_{II} = 20 mm (0.787")
         f_u = 630 N/mm² (91.000 psi)
Tool: **DX 76 / DX 76 PTR and DX 860-ENP**
Fastener: **X-ENP-19 L15**

Knurling on the fastener shank

Fasteners for use in steel base material usually have knurling on the shank so as to improve the resistance to pull-out. The effect of the knurling was shown in a test with fasteners that had knurled and unknurled shanks, but were otherwise the same.

The benefit of knurling is clearly seen from the test results. With virtually the same penetration (actually 106 %), the smooth-shank fastener had only 68 % of the pull-out strength of the knurled-shank type. Even with the penetration increased to 137 %, the pull-out strength was still only 81 % of that of the knurled-shank fastener. In this test, the steel thickness of 10 mm (0.394") allowed through penetration of the steel. If the steel is too thick for through penetration, the beneficial effect of knurling becomes even more pronounced.
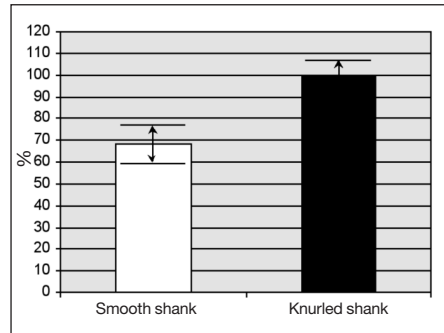
Zinc coating on the fastener shank
Zinc on a fastener shank appears to act as a lubricant that reduces its resistance to penetration into steel. Reduced pull-out strength results because the lower resistance means less heat is generated, thus reducing the welding effect between the shank and the base steel. This was shown in an experiment with fasteners that were identical except for the thickness of zinc coating.

| Steel base material: | t_{II} = 20 mm [0.787"], f_u = 440 MPa [63,817 psi] | | | | | |
|---|---|---|---|---|---|
| Zinc thickness in mm | Average penetration h_{ET} mm / [in.] | % | Average ultimate pull-out load $N_{u,m}$ kN / [kip] | % | Variation CV % |
| ca. 10 | 12.12 [0.477] | 100 | 8.53 / [1.918] | 67 | 25.6 |
| 2–5 | 11.86 [0.470] | 98 | 12.82 / [2.882} | 100 | 9.3 |

Although driving the fastener through sheet metal, as is the case when fastening siding and decking, reduces the negative effect of zinc coating on pull-out strength, the reason for tightly controlling the galvanization process is clear.

Surface of the steel base material

Corrosion protection of structural steel is often achieved by hot-dip galvanizing. Tests have shown that if the fastener penetrates right through the steel, the galvanizing has no significant effect on pull-out strength. In the case of fasteners that do not through-penetrate, pull-out strength is reduced by about 25%. The summary of results from one test is shown below to illustrate these effects.

Average ultimate pull-out loads

Steel thickness 6 mm [0.236"]	Steel thickness 20 mm [0.787"]
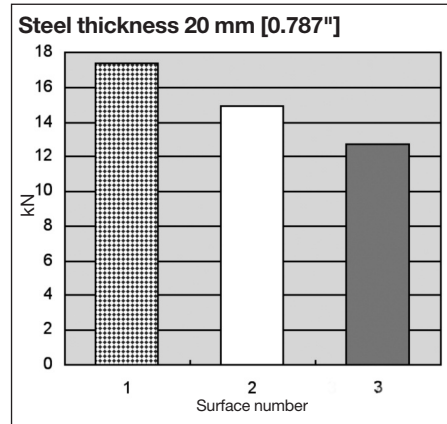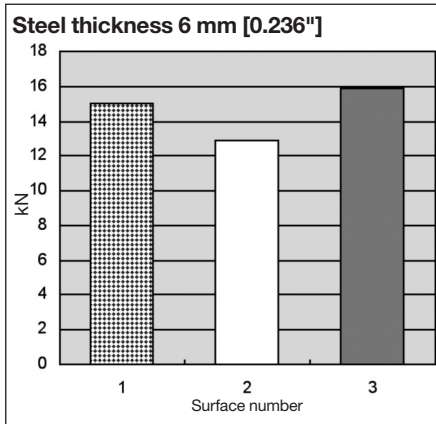
Ultimate tensile strength of steel :
Surface of the steel :

f_u = 430 MPa [62,366 psi]
1. Rough with some slag and rust (reference)
2. Sandblasted
3. Pickled + hot-dip galvanized (min. 60 μm zinc)

Several important observations can be made based on these results:
- Pull-out loads in 6 mm ($^1/_4$") steel base material are much less affected by the surface condition of the steel than they are in 20 mm ($^3/_4$") steel. The reason is that the main anchoring mechanism of through-penetration fastenings is clamping, which is not affected by the surface condition of the steel.
- Hot-dip galvanizing appears to reduce the pull-out strength of non-through-penetrating fastenings by nearly 30%. Note, however, that even with hot-dip galvanizing, the pull-out strength was still 12.5 kN (2.8 kips).
- The negative effect of hot-dip galvanizing is explained by the tendency of zinc on the fastener to act as a lubricant that reduces heat generation during driving. This in turn reduces the tendency of the fastener point to fuse to the base steel. Zinc from the coating on the base steel apparently becomes attached to the fastener as it enters the base steel.

For applications where tensile strength of the fastening is critical and the steel has a heavy coating, the fastening system can be qualified by carrying out pull-out tests on site. If pull-out strength is not adequate, depth of penetration can be increased to improve the situation.

Tensile stress in the steel

The integrity of a powder-actuated fastening is dependent on a relatively smooth pin remaining anchored in structural steel. A large amount of test data, technical assessments, approvals and practical experience with powder actuated fastenings is available to support use of powder-actuated fastening. Performance of fasteners anchored in the steel under tension was investigated by driving fasteners into unstressed steel plates and extracting them with the plates stressed in tension. The steel plates measured 6 × 80 × 455 mm [0.236" × 3.15" × 17.9"] and possessed two different yield stresses - 328.6 MPa [47.7 ksi] and 411.7 MPa [59.7 ksi].

By expressing the steel stress in terms of % of actual yield, it was possible to combine the data for both steel grades and obtain a reasonable curve fit.

Of significance to the designer is the expected decrease in pull-out strength of the fastener at a typical maximum allowable design stress of 60 to 70 % of yield. At this stress, the pull-out strength reduction is less than 15 %. The absolute value in the experiment was still greater than 2 tons.
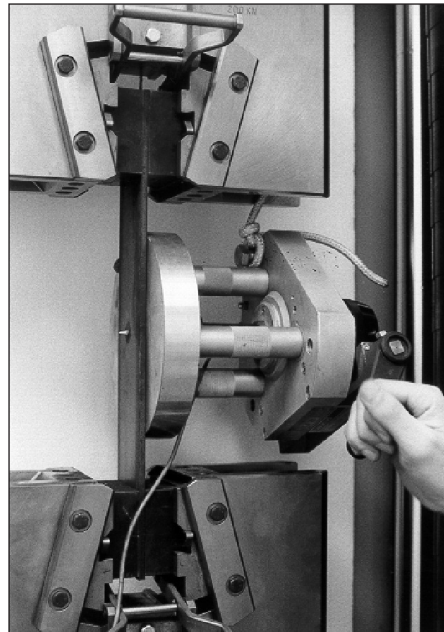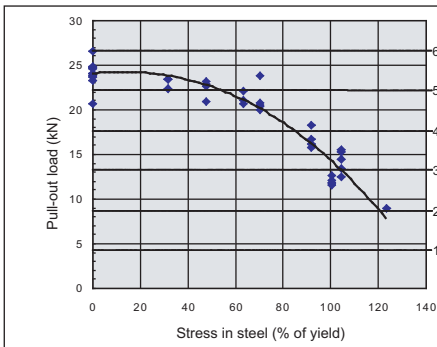
Compressive stress in the steel

Compressive stress in the base steel has no influence on the pull-out strength of the fastener. This was demonstrated by placing fasteners in unstressed 15 mm [0.59"] thick steel plates having a yield strength of 259.3 MPa [37.6 ksi] and extracting them while the plates were compressed in a testing machine.

The minimal variation in pull-out load is simply random variation experienced in testing.
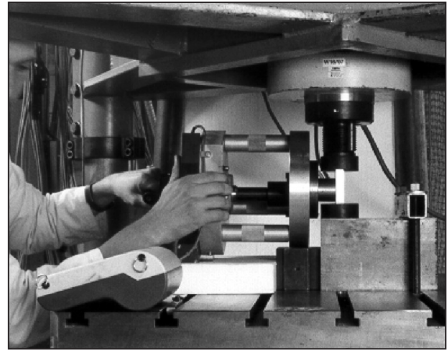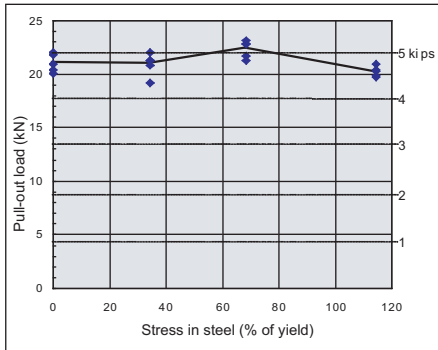
5.3 Suitability of the steel for fastening

There are three main factors determining the suitability of a construction grade steel member for DX fastening:
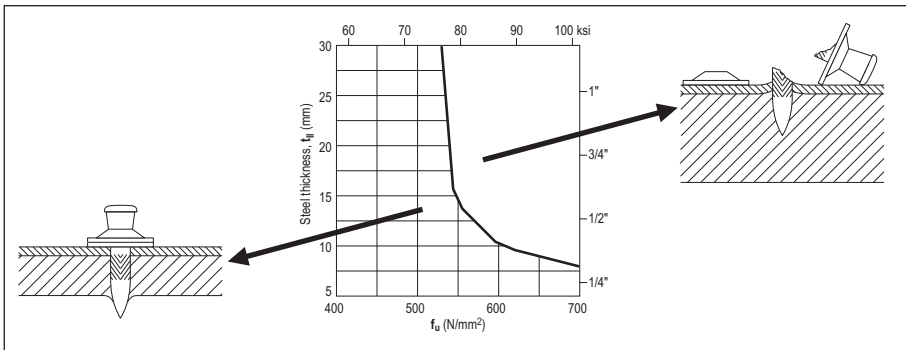• Steel thickness
• Ultimate tensile strength
• Flexibility of the base steel member

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5.4 Application limit diagrams

The application limit of a fastening system is a term applied to a combination of the maximum thickness t_{II} and ultimate tensile strength f_u of steel in which fastenings can be made. There are two general types of application limit diagrams:
• Short fasteners (e.g. siding and decking nails and threaded studs)
• Long fasteners (e.g. nails used to fasten wood to steel)

The application limit line for a **short fastener** is a plot of steel thickness versus ultimate tensile strength. In situations represented by steel thickness / ultimate tensile strength combinations above and to the right of the line, some of the fasteners may shear off during driving. The failure surface will be roughly at a 45° angle to the shank length.


The application limit lines for **long nails** used to fasten **wood to steel** are plots of nail shank length L_s versus steel thickness t_{II}. Each line is valid only for one ultimate tensile strength of steel f_u. Attempts at working to the right of the limit line result in buckled nail shanks.
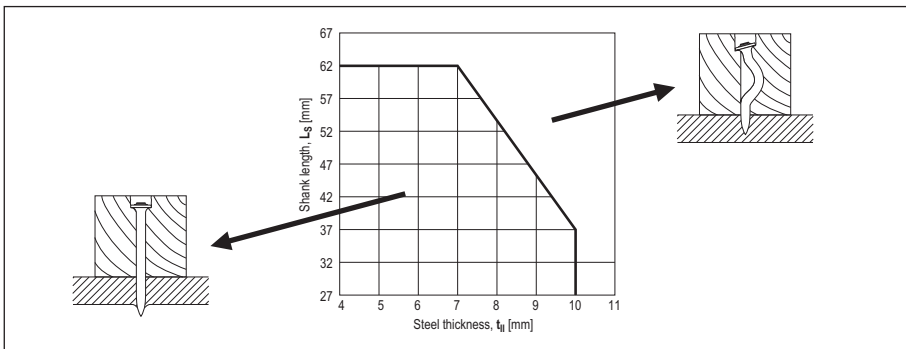
5.5 Thin steel base material

In the context of powder-actuated fastening, steel is considered thin when flange deformation during driving dominates fastener design. When the steel flange is thinner than about 6 mm [0.25"], flange deformation makes use of fasteners with a 4.5 mm [0.177"] shank diameter more difficult and switching to a 3.7 mm [0.145"] shank fastener leads to better results. Use of fasteners with tapered shanks and energy-absorbing washers improves performance and reliability.
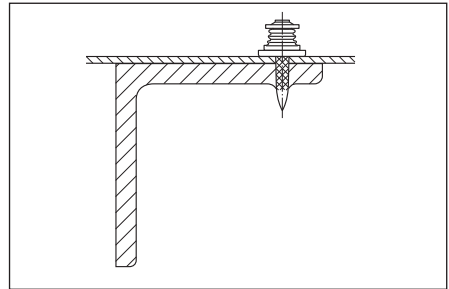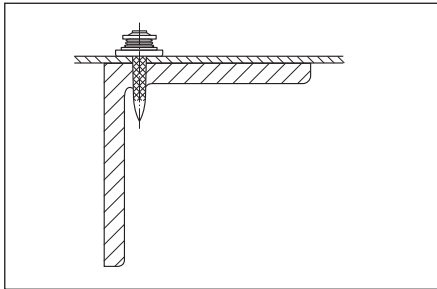
A fastener can penetrate into steel only when the steel (flange) develops a resistance greater than the force required for penetration. This implies the use of energy in excess of that required for penetrating into the steel. In fact, if the driving energy remains constant, fasteners placed closest to the web will be driven deepest. All siding and decking fasteners should have a mechanism to clamp the sheets down tightly over the entire range of allowable standoffs. This is especially critical for fasteners used for fastening to thin steel.

Obviously, under shear loading, failure of the base material is more likely with thin steel than with thick steel. When approving fastening systems for a project, it is important to consider whether the system has actually been tested with thin base steel or not.

Hilti's general recommendation for thin base steel fasteners is to place the fastenings within $\mathbf{b_x} = 8 \times \mathbf{t_{II}}$ of the web.
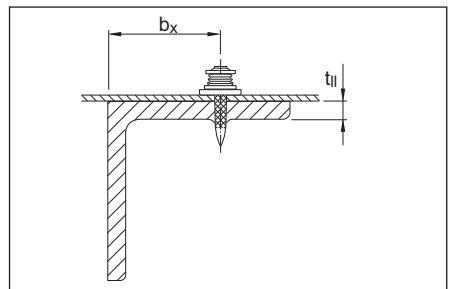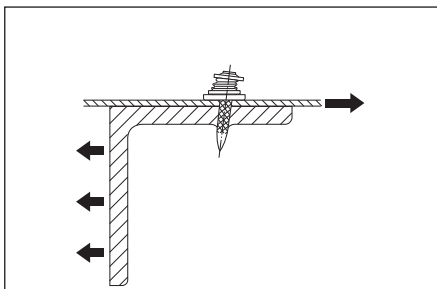
5.6 Types of load and modes of failure

5.6.1 Shear loads
The shear loads acting on siding and decking fasteners come from:
• Diaphragm action of the fastened sheets
• Forces of constraint (for example due to temperature changes)
• Self-weight of siding material

Testing
Shear testing of siding and decking fastenings is done using specimens made up of a strip of sheet metal fastened to a steel plate. Suitable, non-slip fixtures have to be used at either end. In some cases specimens are bent up at the sides to hinder eccentricity.

Failure of the fastened material
The load-deformation curves of shear tests with powder-actuated fasteners show a nearly ideal behavior. After an initial elastic phase during which the clamping force of the washers against the sheet metal is overcome, the sheet metal reaches its yield stress in an area where the fastener bears against it. Then the fastener shank cuts through the sheet metal until the end of the sheet is reached. The large area under the load-deformation curve represents energy absorbed, and this is what makes the fastening method ideal for diaphragms.
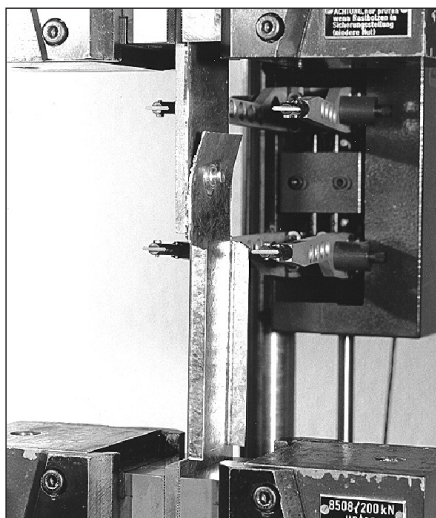
Failure of the base steel

If the thickness of the fastened sheet metal is large compared to the base steel thickness, bearing failure of the base material is a possible mode of failure.

Pull-out from the base steel

The unavoidable eccentricity in the shear test specimen leads to a tensile load component on the fastener. Thick fastened material and thin base material is also involved in this mode of failure. This failure mode is generally not governing for base material thickness of t_{II} > 6 mm.
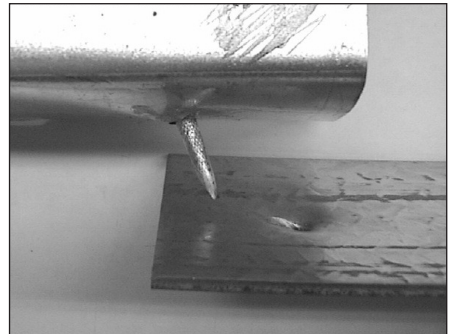
Fracture of the fastener

About 20 kN (4.5 kips) of force is required to shear the Ø 4.5 mm (0.177") shank of an **X-ENP-19 L15** fastener. With about 2.5 mm (12 gauge) thick steel sheet as fastened material, a force of this magnitude could be possible. The force needed to break a Ø 3.7 mm (0.145") shank of an **X-EDNK22 THQ12** fastener is about 13 kN (2.9 kips). This force can be generated with 1.5 mm (16 gauge) sheet steel. In practice, this failure mode is likely only where expansion joints are not provided to relieve forces of constraint from temperature differences.
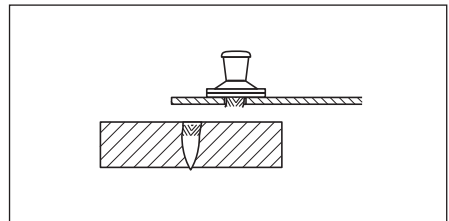
5.6.2 Tensile loads

The most common source of tensile loading on siding and decking fasteners comes from wind suction acting on the roof or wall cladding. In diaphragms, fasteners can be subject to tensile loads in situations where the combination of geometry and thickness of decking fastened leads to prying. In designs with very stiff decking and wide beams or unbalanced spans, prying can also be caused by concentrated loads.

Testing

Tensile testing of siding and decking fastenings is carried out using specimens made up of a trapezoidal-shaped piece of sheet metal fastened to a steel plate. Suitable, vice-like fixtures are used to grip the specimen. This is often referred to as a pull-over test because the common failure mode is the sheet pulling over the washers or the head of the fastener. If the sheet thickness fastened is increased so that pull-over does not govern, pull-out will be the failure mode.

Some fasteners like the Hilti X-ENP have a head that can be gripped and pulled out by a suitable fixture. With these fasteners, a pull-out test can still be done even if pull-over is the original mode of failure. This fastener type has the further advantage of allowing in-place fasteners on a jobsite to be tested.
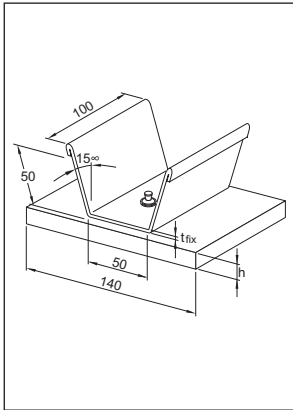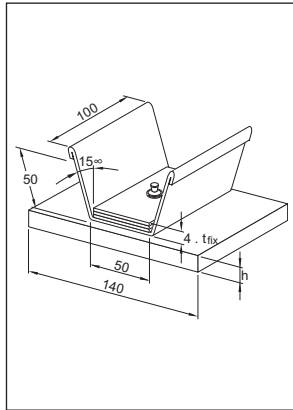
| Pull-over test specimen | Pull-over test specimen with 3 extra layers to simulate end lap – side lap | Test setup |
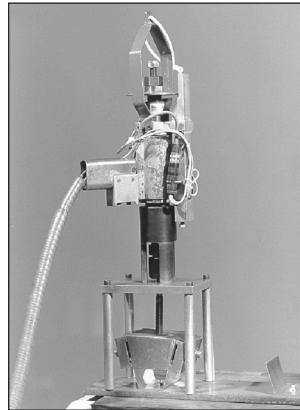
Sheet pull-over

In this failure mode, the sheet tears and is lifted up over the fastener head and washers. Depending on the sheet thickness and tensile strength, the washers may be bent up.

Washer pull-over

Another possible failure mode is that of the washers being pulled up over the head of the nail. Obviously, this happens when the sheet is somewhat stronger and /or thicker than when sheet pull-over occurs. This failure mode is also heavily dependent on fastener design.
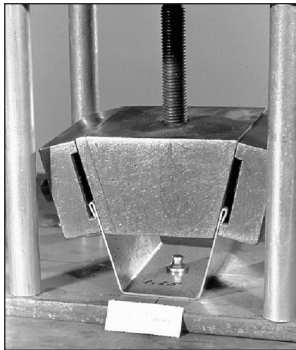
Pull-over test specimen at test start Sheet pull-over   Washer pull-over
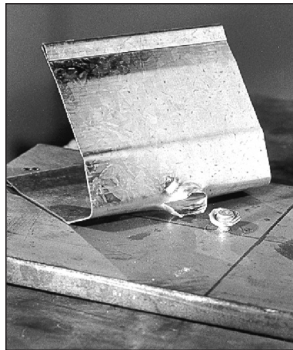
Pull-out from the base steel

As sheet thickness and number of layers is increased, this failure mode becomes more likely. For a properly driven **X-ENP-19 L15** pull-out from the base steel is not a likely mode of failure. The head and washer design of the **HSN24** or **X-EDNK22 THQ12** fasteners can allow this failure mode, especially with multiple layers of sheets.

Fracture of the fastener

A force of more than 30 kN [6.7 kips] is required to break the Ø 4.5 mm [0.177"] shank of an **X-ENP-19 L15** fastener and, even if sheet or wa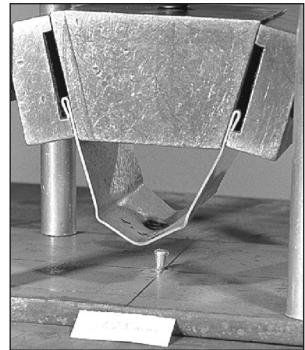sher pull-over does not govern, pull-out strengths of this magnitude are not very common. This mode of failure will therefore hardly ever occur with these heavy-duty fasteners. The Ø 3.7 mm [0.145"] shank of an **X-HSN 24** or **X-EDNK22 THQ12** fastener may break at about 20 kN [4.5 kips] tension. Since these smaller fasteners will pull out at a force of 8 to 15 kN [1.8–3.3 kips], fractures due to tensile loads are rare. If fractured fasteners of this type are found on a jobsite, the most likely cause is that the application limit has been exceeded (the base steel is too hard and/or too thick for the pin).

Cyclic loading

Siding and decking nails used in wall and roof construction are subject to cyclic loading from wind suction. Cyclic load testing is carried out to determine characteristic resistance and allowable (recommended) loads. The approval requirements of the European Technical Approval ETA prepared by DIBt (Deutsches Institut für Bautechnik) govern the design-relevant number of load repetitions (5,000) and the necessary safety factors. Notes in this regard are found on the corresponding product data sheets.

If the fastener will be subjected to a large number of load repetitions and fatigue, we recommend carrying out a design check according to the requirements of Eurocode 3 (or similar code). Eurocode 3 gives the characteristic fatigue resistance and safety concept for steel

construction. To carry out the check according to Eurocode 3 it is necessary to have a statistical analysis of test data obtained under the application conditions. Except for siding and decking fasteners, the applicable product data sheets limit the validity of recommended loads to predominantly static loading. If a design analysis has to be carried out for true fatigue loading, test data can be obtained from Hilti. Examples of such data are shown below.

X-EM8-15-14
(standard zinc-plated fastener)

The X-EM8-15-14 has a shank diameter of 4.5 mm and a hardness of HRC 55.5 (f_u = 2,000 MPa). The ΔF-N diagram shows the load range ΔF for a lower load of 0.05 kN. The individual test results are displayed as points and the curves show average and characteristic (95% survival probability) values. The failure mode was shank fracture or fracture in the M8 threading.

The recommended load for predominantly static loading is 2.4 kN. Comparing this value to the ΔF-N diagram will lead to the conclusion that X-EM8-15-14 fastenings designed for 2.4 kN static loading will survive a large number of load repetitions. The fastenings can be said to be robust, even when the actual loading turns out to be in part cyclic.
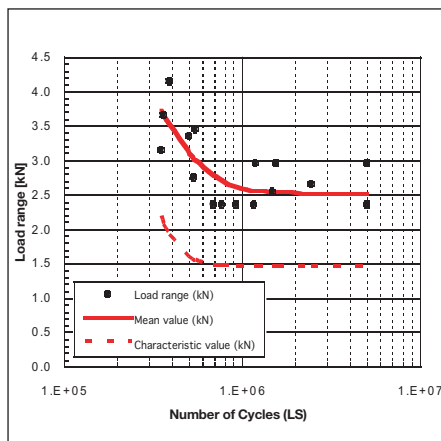
X-CRM8-15-12 (stainless steel fastener)

The X-CRM8-15-12 has a shank diameter of 4.0 mm and a minimum ultimate tensile strength of 1,850 MPa. The ΔF-N diagram shows the load range ΔF for a lower load of 0.05 kN. The individual test results are displayed as points. The failure mode was shank fracture or fracture just below the head of the stud.
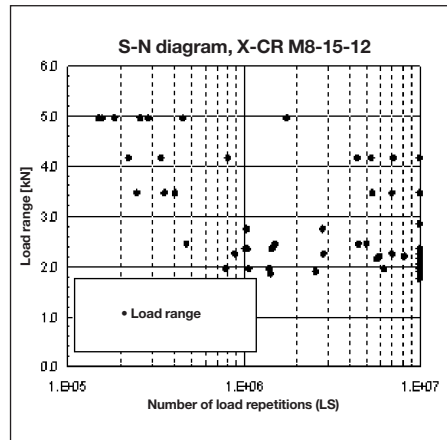
The recommended load for predominantly static loading is 1.8 kN. Comparing this value to the ΔF-N diagram will lead to the conclusion that X-CRM8-15-12 fastenings designed for 1.8 kN static loading will survive a large number of load repetitions. The fastenings can be said to be robust, even when the actual loading turns out to be in part cyclic.

S-N diagram, X-CR M8-15-12

Mode of failure under cyclic loading

A major finding of cyclic loading tests is that the strength of a DX fastening subject to cyclic loading is not limited by failure of the anchorage. It is only when the number of cycles is very low – i.e. predominantly static loading – that nail pull-out is observed. The two schematic diagrams below show the relationship between failure mode and number of cycles. All tests show that the anchorage of DX fasteners in steel and in concrete is extremely robust with regard to resisting cyclic loading. Fasteners subject to a large number of load repetitions fracture in the shank, head or threading. A condition for obtaining this behaviour is that the fasteners are correctly driven. Fasteners that are not driven deeply enough exhibit low pull-out strength and in a cyclic loading test may not necessarily fail by fracture.

Effect of number of cycles on failure mode
DX fastener in steel (correctly placed)

Load range

Fastener pull-out

Fastener fracture

| 1 | 10^2 | 10^4 | 10^6 | 10^8 |

Number of load cycles
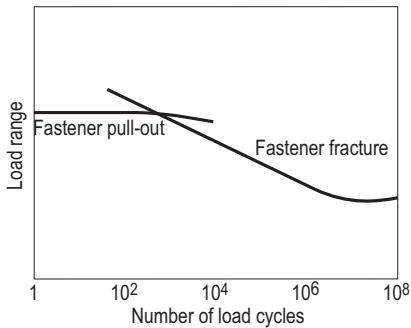
Effect of number of cycles on failure mode
DX fastener in steel (incorrectly placed)

Load range

Fastener fracture

Fastener pull-out

| 1 | 10^2 | 10^4 | 10^6 | 10^8 |

Number of load cycles
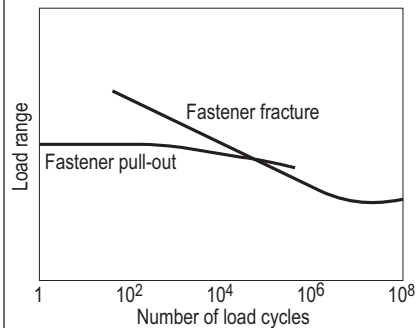
In older product information and data sheets, this basic suitability of DX fasteners for cyclic loading was emphasized by defining the recommended loads as cyclic recommended loads. At the time that this product information was assembled, a true safety concept for a strict check of DX fastenings subject to fatigue loading was not available. With Eurocode 3, this is today available. If a fatigue design analysis is carried out, it is important – as with static design – that adequate redundancy be provided.

Failure of the sheet
In cyclic load tests, failure of the steel sheet itself is common.

5.7 Effect of fasteners on structural steel

Driving powder- or gas-actuated fasteners into a steel member does not remove steel from the cross-section, but rather displaces steel within the cross-section. It is therefore not surprising that tests like those described in following sections show that both drilled holes and screws, either self-drilling or self-tapping, reduce the strength of a cross-section more than powder-actuated fasteners.

The results of the tests can also be used to show that it is conservative to consider a powder-actuated fastener as a hole. This allows the effect of fasteners in a steel member subject to static loading to be taken into consideration.

Fatigue seldom needs to be considered in building design because the load changes are usually minor in frequency and magnitude. Full design wind and earthquake loading is so infrequent that consideration of fatigue is not required. However, fatigue may have to be considered in the design of crane runways, machinery supports, etc. The S-N curves resulting from fatigue tests of steel specimens with fasteners installed are also presented.

5.7.1 Effect on the stress-strain behaviour of structural steel

The effect that powder-actuated fasteners (PAF's) have on the stress-strain behaviour of structural steel was investigated in a systematic test programme using tensile test specimens containing PAF's, self-drilling screws and drilled holes. A control test was carried out using specimens without any holes or fasteners.

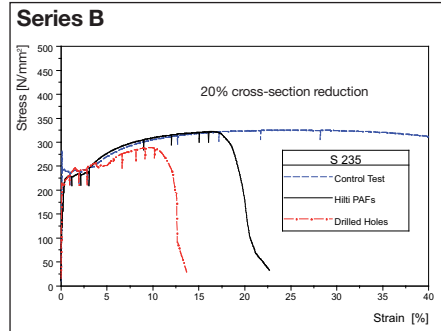| Series A:	Series B:
• ASTM 607, grade 50	• S235 and S355 steel
• Cross-section 3.42 x 74 mm [0.135 x 2.913"]	• Cross-section 6 x 45 mm [0.236 x 1.772"]
• X-EDNK22 powder-actuated fasteners, shank diameter 3.7 mm [0.145"]	• Powder-actuated fasteners, shank diameter 4.5 mm [0.177"]
• Drilled holes, diameter 3.7 mm [0.145"]	• Drilled holes, diameter 4.5 mm [0.177"]
• Self-drilling screws, shank diameter 5.5 mm [0.216"]	

The figures below show representative stress-strain curves for the tests (the plotted stress is based on the gross cross-section). Note that the line for the powder-actuated fasteners follows the control test line more closely than the lines for drilled holes or self-drilling screws.
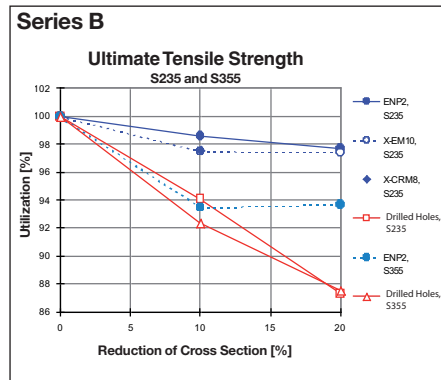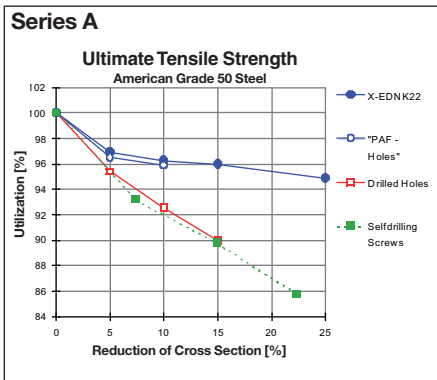
Series A

15% cross-section reduction

ASTM 607, Grade 50
- Control Test
- Selfdrilling Screws
- Hilti PAFs
- Drilled Holes

Stress [N/mm²] vs Strain [%]

LOAD_DEFORMATION_SERIES_A

Series B

20% cross-section reduction

S 235
- Control Test
- Hilti PAFs
- Drilled Holes

Stress [N/mm²] vs Strain [%]
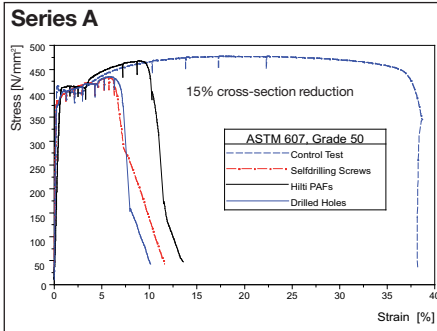
LOAD_DEFORMATION_SERIES_B

The test results were evaluated in terms of utilization as a measure of ultimate strength. Utilization is the ultimate load of a sample expressed as a percent of the ultimate load of the control test.

Series A

Ultimate Tensile Strength
American Grade 50 Steel

Utilization [%] vs Reduction of Cross Section [%]

- X-EDN K22
- "PAF - Holes"
- Drilled Holes
- Selfdrilling Screws

Series B

Ultimate Tensile Strength
S235 and S355

Utilization [%] vs Reduction of Cross Section [%]

- ENP2, S235
- X-EM10, S235
- X-CRM8, S235
- Drilled Holes, S235
- ENP2, S355
- Drilled Holes, S355

Graphs of the utilization versus cross-section reductions show that:
• The utilization for PAFs is clearly better than that of drilled holes or self-drilling screws.
• The hole left by a removed PAF has the same effect as when the PAF is left in place.
• Increasing the number of PAFs across a section from one to two or more has a proportion-ally smaller effect on utilization than placement of the first fastener.

More detailed information on the test program and findings is published in the paper **Powder-actuated fasteners in steel construction** (and the referenced literature), published in the STAHLBAU-Kalender 2011 (Publisher Ernst & Sohn, 2011, ISBN 978-3-433-02955-8). English Reprints of the paper can be distributed per request.

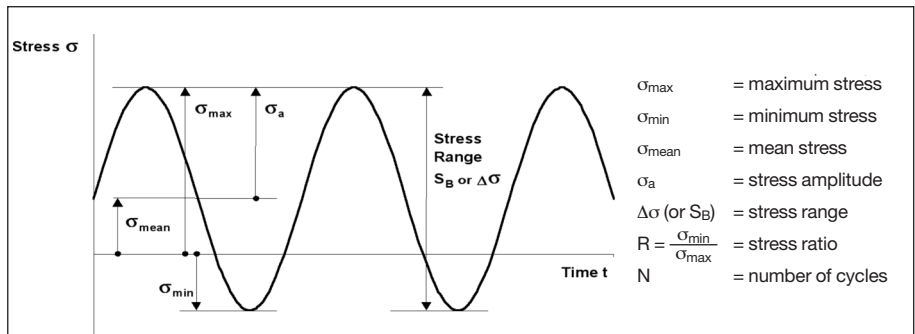### 5.7.2 Effect on the fatigue strength of structural steel

During the late 1970s and early 1980s, a fatigue testing program consisting of 58 tests with over 1,100 specimens was carried out at the University of Darmstadt in Germany. The reason for the research at that time was to support the use of powder-actuated fasteners for attaching noise-dampening cladding to railway bridges in Germany.

Parameters investigated in those tests are shown in following table:

Steel grade	Steel thicknesses	Stress ratio **R**	Imperfections
S 235 (St 37) / A36 S 355 (St 52) / grade 50	6, 10, 15, 20, 26.5, 40, 50 mm [0.236, 0.394, 0.591, 1.043, 1.575, 1.969"]	0.8, 0.5, 0.14, -1.0, -3.0	Fastener: - installed and pulled out, - inclined installation and pulled out - inclined installation

Loading conditions
The terminology and notation is shown in the illustration below.

σ_{max} = maximum stress
σ_{min} = minimum stress
σ_{mean} = mean stress
σ_a = stress amplitude
$\Delta\sigma$ (or S_B) = stress range
$R = \dfrac{\sigma_{min}}{\sigma_{max}}$ = stress ratio
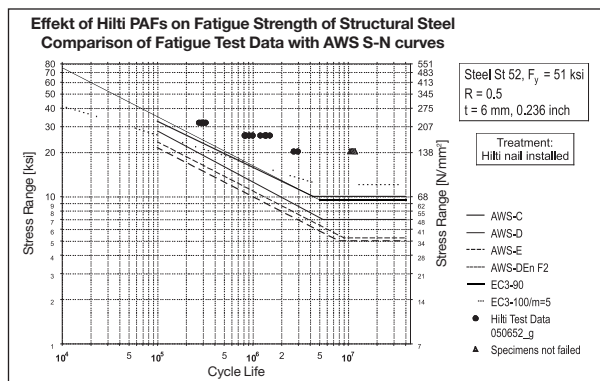N = number of cycles

Fasteners tested

The primary fastener used in the tests was the Hilti ENP3-21 L15, the forerunner of the ENP2-21 L15. The difference is in the head shape, which has no effect on interaction with the base steel. Tests were also performed with the ENP2-21 L15, ENP3-21 D12 and the EM8-11-14 threaded stud, all of which have 4.5 mm diameter knurled shanks.

| ENP3-21 L15 | ENP2-21 L15 | ENP3-21 D12 | EM8-11-14 P8 |
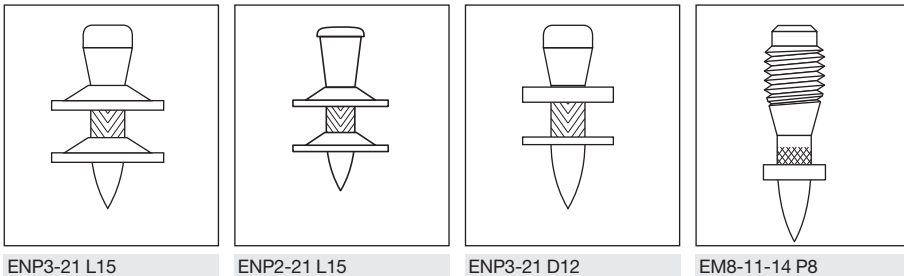
The results of the tests were evaluated by Niessner and Prof. T. Seeger from the University of Darmstadt in accordance with the provisions of Eurocode 3. An example plot of one test series is given at the right. The graph allows for a comparison with European fatigue categories 90 (m = 3) and 100 (m = 5) as well as American categories according to AWS-provisions.

Effekt of Hilti PAFs on Fatigue Strength of Structural Steel Comparison of Fatigue Test Data with AWS S-N curves

Steel St 52, F_y = 51 ksi
R = 0.5
t = 6 mm, 0.236 inch

Treatment:
Hilti nail installed

—— AWS-C
—— AWS-D
---- AWS-E
----- AWS-DEn F2
—— EC3-90
···· EC3-100/m=5
● Hilti Test Data 050652_g
▲ Specimens not failed

Stress Range [ksi]

Stress Range [N/mm²]

Cycle Life

Conclusions

- The effect of driving a Hilti powder-actuated fastener on the fatigue strength is well known and predictable.
- The constructional detail "Effect of powder-actuated fasteners on base material" (unalloyed carbon steel) was evaluated by Niessner and Seeger from the University of Darmstadt in compliance with Eurocode 3.
- The EC 3 detail category 90 with m = 3 or the detail category 100 with m = 5 is alternatively applicable.
- Wrong fastener installations as popped out or inclined fasteners are covered. Piston marks in the base material due to wrong use of the tool without a fastener or notches due to fasteners failed during the installation have to be removed by appropriate measures.

More detailed information on the evaluation of the test data and the test program is published in the paper "Fatigue strength of structural steel with powder-actuated fasteners according to Eurocode 3" by Niessner M. and Seeger T. (Stahlbau 68, 1999, issue 11, pp. 941-948).
English reprints of this paper can be distributed per request.