Hilti X-BT Threaded Fastener Specification

Supplement 11/2011

Use in spheroidal cast iron

Approval update - Fatigue classification

November 2011

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Preface

The specification of the Hilti X-BT threaded fastener is published in the brochure ***Hilti X-BT Threaded Fastener Specification***, issue December 2010 [1].

This specification contains

- Application description
- Technical data
- Method statement
- Description of technical performance
- Approval survey
- Customer testimonials

This supplement predominantly deals with the extension of the use of X-BT fasteners which are driven to cast iron base materials. Additionally an approval update – compared with the status from end of 2010 [1] – will be given.

In general this supplement needs to be read in conjunction with the ***Hilti X-BT Threaded Fastener Specification***, issue December 2010 [1]. Figure 1 gives an overview of the X-BT fasteners with sealing washer. Furthermore, Figure 1 summarizes the most relevant technical data when the X-BT fasteners are driven into unalloyed carbon steel.

 **X-BT M10-24-6 SN12-R** **X-BT W10-24-6 SN12-R**	 **X-BT M8-15-6 SN12-R**	 **X-BT M6-24-6 SN12-R** **X-BT W6-24-6 SN12-R**
Typical application: Fastening of cables, cable ladders, T-bars, grounding	Typical application: Fastening of grating and Hilti M-channels	Typical application: Fastening of electrical junction boxes
Recommended working loads according to [1] and [2]: Base material S235 (A36) : Tension: N_{rec} = 1.8 kN (405 lbs), Shear: V_{rec} = 2.6 kN (517 lbs) Base material S355 (Grade 50) : Tension: N_{rec} = 2.3 kN (584 lbs), Shear: V_{rec} = 3.4 kN (764 lbs)		

Figure 1. Survey of Hilti X-BT threaded fasteners

With respect to further details on the fasteners, method statement and quality control it is referenced to [1].

When driving the X-BT fasteners into cast iron components, the method itself, the cartridge recommendation, the use of the respective tool and the stand-off requirements remain unchanged, details see [1].

1. Technical data for X-BT fastenings made to cast iron with spheroidal graphite

1.1 Cast iron specification

Components made from cast iron with spheroidal graphite are typically used in the nacelle of wind towers. The preferred grade is EN-GJS-400-18-LT according to EN 1563 with a minimum ultimate strength of 400 N/mm² (for thickness $t \leq 30$ mm), a minimum fracture strain A of 18 % and with impact toughness properties suitable for use in cold temperatures. The use of cast iron with spheroidal graphite allows economical production of complex machinery parts combined with ductile material behaviour.

The presence of spherical graphite is required to allow the casting process. Figure 2 shows a representative example of a micro section of cast iron EN-GJS-400-18-LT. The distribution of the spheroidal graphite in the ferritic matrix is clearly visible.

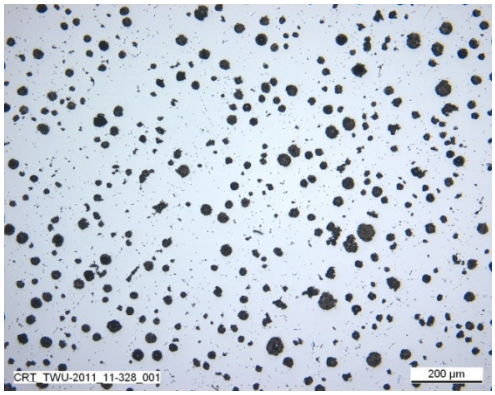


Figure 2. Micro section of cast iron EN-GJS-400-18LT:
Spheroidal graphite embedded in ferritic matrix

The cast iron needs to meet the following specification given in Table 1. The listed carbon content and microstructure is typical for EN-GJS-400-18-LT used in the nacelle of wind towers.

Table 1. Requirements of spheroidal graphite cast iron base material

Subject	Requirements
Cast iron	Spheroidal graphite cast iron according to EN 1563
Strength class	EN-GJS-400 to EN-GJS-600 according to EN 1563
Chemical analysis and amount of carbon	3.3 - 4.0 mass percentage
Microstructure	Form IV to VI (spherical) according to EN ISO 945-1:2010 Minimum size 7 according to Figure 4 of EN ISO 945-1:2010
Material thickness	$t_{II} \geq 20$ mm

1.2 Fastening tool and components

The following Table 2 provides an allocation between the threaded fasteners and the respective X-BT system components. In general, the use of X-BT fasteners with sealing washers (see Table 1) is recommended.

Table 2. X-BT fasteners and respective system components

Fastener	Fastening tool and components	Cartridge	Step shank drill
X-BT M10-24-6 SN12-R (item no: 377078) X-BT M10-24-6-R *) (item no: 377077) X-BT M6-24-6 SN12-R (item no: 432266)	Tool: DX 351 BT Fastener guide: X-351-BT FG M1024 (item no: 378674) Piston: X-351-BT P 1024 (item no: 378676)	6.8/11 M brown High Precision (item no: 377204)	TX-BT 4/7-80 (item no: 377079) TX-BT 4/7-110 (item no: 377080) TX-BT 4/7-150 (item no: 377081)
X-BT W10-24-6 SN12-R (item no: 377076) X-BT W10-24-6-R *) (item no: 377075) X-BT W6-24-6 SN12-R (item no: 432267)	Tool: DX 351 BT Fastener guide: X-351-BT FG W1024 (item no: 378673) Piston: X-351-BT P 1024 (item no: 378676)		
X-BT M8-15-6 SN12-R (item no: 377074) X-BT M8-15-6-R *) (item no: 377073)	Tool: DX 351 BTG Fastener guide: X-351-BT FG G (item no: 378675) Piston: X-351-BT P G (item no: 378677)		

*) without sealing washer

The three step shank drills only differ in their length. Their optimized use depends on the accessibility condition on the jobsite. The recommended tool energy setting = 1 (if required, increase of energy setting based on job site tests).

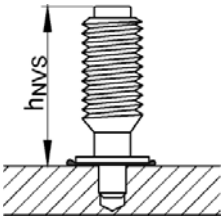


Figure 3.
Fastener stand-off

The fastener stand-off range remains unchanged as follows:

- h_{NVS} = 15.7 – 16.8 mm for X-BT M8
- h_{NVS} = 25.7 – 26.8 mm for X-BT M6/W6 and X-BT M10/W10

1.3 Load data

Table 3 summarizes the recommended working loads for the X-BT fasteners driven into cast iron.

Table 3. Recommended loads for X-BT fasteners and cast iron base material

Loading direction	Recommended loads
Tension	N_{rec} = 0.5 kN (115 lbs)
Shear	V_{rec} = 0.75 kN (170 lbs)
Bending	M_{rec} = 8.2 Nm (6 ftlb)

The installation torque T_{rec} amounts to 8 Nm (5.9 ftlb).

Conditions for the recommended loads:

- Global factor of safety for static pull-out: ≥ 3 (based on 5% fractile), ≥ 5 (based on mean value)
- Minimum edge distance = 6 mm (1/4")
- Dynamic load variation is covered

Table 4 shows the recommended interaction formula in case of combined loading:

Table 4. Recommended interaction formula

Combined loading situation	Interaction formula
V – N (shear and tension)	$\frac{V}{V_{rec}}+\frac{N}{N_{rec}}\le 1.2$ with $\frac{V}{V_{rec}}\le 1.0$ and $\frac{N}{N_{rec}}\le 1.0$
V – M (shear and bending)	$\frac{V}{V_{rec}}+\frac{M}{M_{rec}}\le 1.2$ with $\frac{V}{V_{rec}}\le 1.0$ and $\frac{M}{M_{rec}}\le 1.0$
N – M (tension and bending)	$\frac{N}{N_{rec}}+\frac{M}{M_{rec}}\le 1.0$
V – N – M (shear, tension and bending)	$\frac{V}{V_{rec}}+\frac{N}{N_{rec}}+\frac{M}{M_{rec}}\le 1.0$

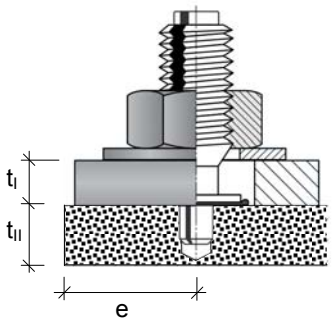
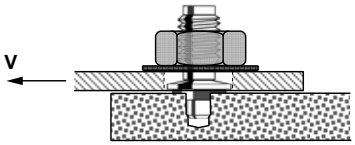
V, N and M correspond with the maximum working loads (see internal forces in Table 5) acting on the fastening.

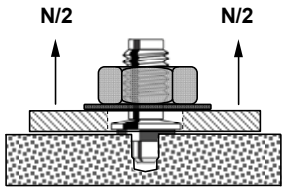
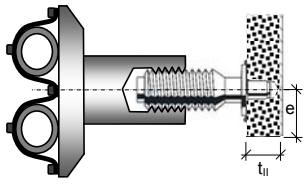
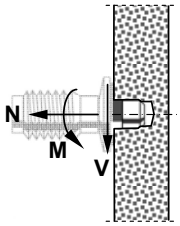
Note: Table 4 also applies in case of carbon steel or stainless base material.

1.4 Connection types and application range

Table 5 summarizes the possible types of connection, the corresponding loading and the respective range of application.

Table 5. Types of connection and corresponding loading conditions, range of application

<table>
<tr><th>Type of connection</th><th>Type of loading</th><th>Range of application</th></tr>
<tr><td rowspan="2">Connections of steel sheets or plates to cast iron base material
 
</td><td>Lateral shear loading
 
</td><td rowspan="2">Fastened material (component I):
Structural carbon steel or corrosion resistant steel according to EN 10025, EN 10346 and EN 10088-2 with:
▪ $R_m \geq 330$ N/mm^2
▪ t_I for studs with sealing washer:
1 mm $\leq t_I \leq$ 14 mm for X-BT M6/W6
2 mm $\leq t_I \leq$ 7 mm for X-BT M8
2 mm $\leq t_I \leq$ 15 mm for X-BT M10/W10
▪ t_I for studs without sealing washer:
10 mm $\leq t_I \leq$ 15 mm for X-BT M10/W10

Cast iron base material (component II):
Spheroidal graphite cast irons according to EN 1563 with:
▪ 400 N/mm$^2 \leq R_m \leq$ 720 N/mm^2
▪ Microstructure and chemical analysis as given in Table 1
▪ $t_{II} \geq 20$ mm
▪ Minimum edge distance: e $\geq$ 6 mm</td></tr>
<tr><td>Tensile loading
 
</td></tr>
<tr><th>Type of connection</th><th>Type of loading</th><th>Range of application</th></tr>
<tr><td>Connection of installation devices to cast iron base material
 
</td><td>Shear, tension and bending loading
 
</td><td>Cast iron base material (component II):
Spheroidal graphite cast irons according to EN 1563 with:
▪ 400 N/mm$^2 \leq R_m \leq$ 720 N/mm^2
▪ Microstructure chemical analysis as given in Table 1
▪ $t_{II} \geq 20$ mm
▪ Minimum edge distance: e $\geq$ 6 mm</td></tr>
</table>

1.5 Grounding and bonding restrictions

No corresponding experimental investigations have been made so far. There, the use of X-BT fasteners for grounding and bonding application is not covered, in case the fasteners are driven to cast iron components.

1.6 Performance review

In order to investigate the influence of cast iron base material on the performance of X-BT fasteners a comprehensive test program was run. The scope of the program included the following experimental investigations (summary and assessment in [3]):

- Static pullout tests
- Static shear and bending tests
- Tension fatigue tests
- Tests to cover the effect of the edge distance
- Tests to cover the effect of the cast iron surface

Compared with the performance of X-BT fasteners in unalloyed structural steel (see Figure 1, [1] and [2]), the recommended load values are smaller due to the presence of the graphite in the cast iron. As with unalloyed structural steel, reliable anchorage of the X-BT fastener develops also in case of cast iron base material. The anchorage is also caused by predominantly friction welding between the fastener shank and the ferritic or perlitic matrix of the cast iron. However, the presence of the graphite reduces the effective contact area, which explains the reduction of the pullout strength.

Furthermore, the recommended loads cover implicitly effects of dynamic and variable loading on the fastener. This statement is based on the results of tension fatigue tests, which were performed to investigate the robustness of the anchorage of X-BT fasteners in cast iron, see Figure 4 and 5.

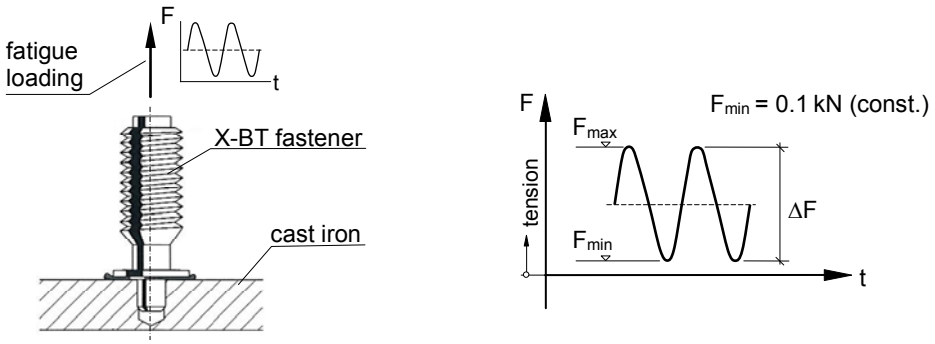


Figure 4. Principle sketch of cyclic tension tests

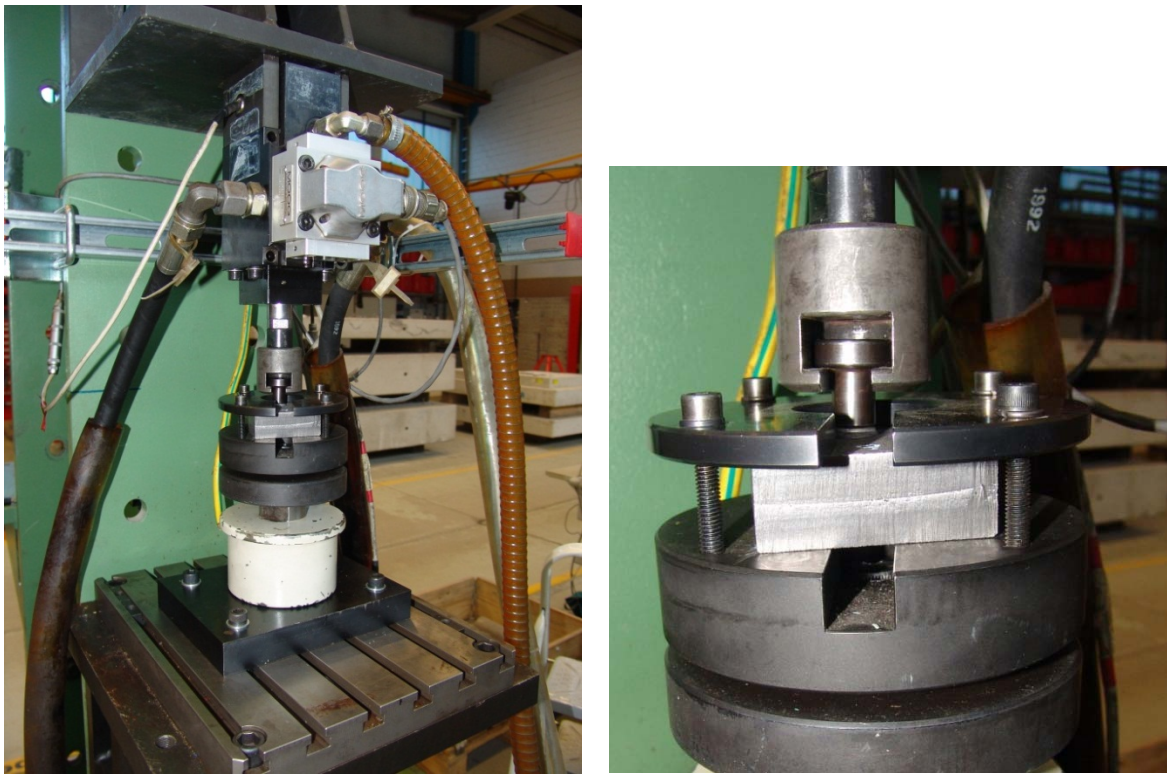


Figure 5. Servo-hydraulic test setup for tension fatigue tests

Conclusions from the cyclic tension tests:

- The anchorage of the X-BT does not work loose. In none of the tests pull-out of the fastener from the cast iron was the controlling mode of failure.
- Failure was controlled by fatigue fracture of the stainless stud material. The fractures occurred at upper loads significantly beyond the recommended tension load of 0.5 kN.
- For final verification and with respect to the reported design life of wind towers, two fatigue tests were performed with an upper load of 1.0 kN (which is double the recommended tension load) and a target number of 200 million load cycles.
- Both long run samples passed the test without any damage, neither to the fastener material nor to the anchorage. Residual static pullout tests of these two samples resulted in a pullout strength beyond 5 kN.
- The test results clearly verify reliable X-BT fastenings to cast iron EN-GJS-400-18LT used in the nacelle of wind towers.

Figure 6 shows a graph of the fatigue test results performed with X-BT fasteners. The load-level of the run-outs is by far beyond the recommended working load of 0.5 kN, especially see the two run-outs at 200 million load cycles with an upper load of 1.0 kN.

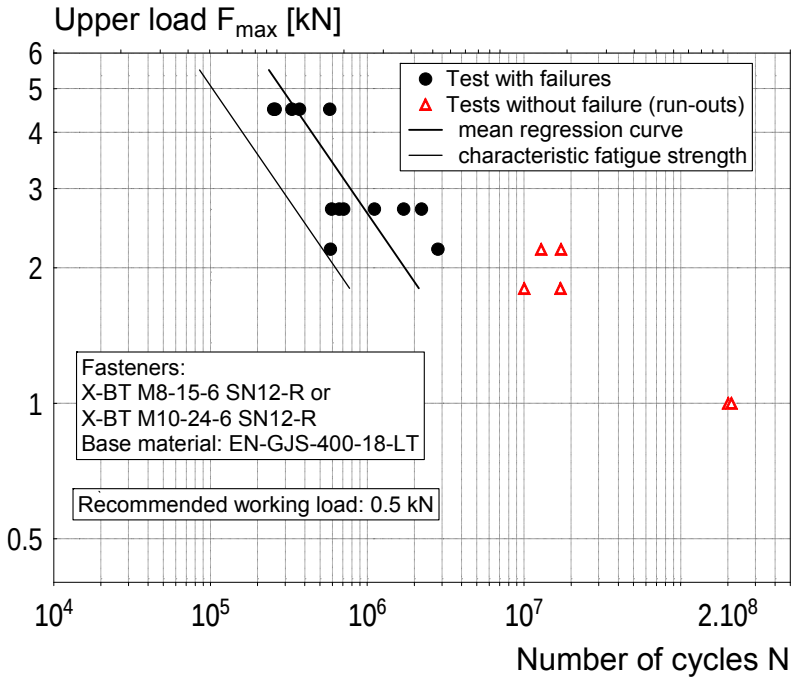


Figure 6. Results of cyclic tension tests

It is further planned to add the use of X-BT fasteners on cast iron components into the X-BT Type Approvals issued by GL [4] and DNV [5].

2 Approval update

2.1 Modifications and updates since December 2011

Compared with the state of the issue of [1], several approval updates were made in 2011. Therefore, Table 6 summarizes the current approval state including a brief survey of the respective modifications.

Table 6. State of X-BT approvals, November 2011

Approval Body	State of approval in [1], Dec. 2010	Current state of approval, Nov. 2011	Modification
GL – Germanischer Lloyd	Certificate: 12272-10HH	Updated Certificate: 12272-10HH (Nov. 4, 2011)	• Extension of use to steel towers for wind turbines • Addition of M6/W6 types • Addition of HCR high corrosion resistant shank materials (1.4529) • Addition of grounding application *) • Allowance of use on structural members requiring fatigue design • Fatigue category definition in compliance with Eurocode 3, EN 1993-1-9 (see chapter 2.2.2)
DNV – Det Norske Veritas	Certificate: S-5624	New Certificate: S-6751 (Oct. 26, 2011)	• Extension of use to steel towers for wind turbines • Addition of M6/W6 types • Addition of HCR high corrosion resistant shank materials (1.4529) • Addition of grounding application *) • Improvement of fatigue category in compliance with DNV-RP-C203 (see chapter 2.2.2)
ABS – American Bureau of Shipping	Certificates: 03-HS369456-1-PDA, off-shore, 03-HS369884-1-PDA, shipbuilding	Updated Certificate: 03-HS369456-3-PDA (Sep. 12, 2011)	• Merging of previous 2 certificates into one, which covers both off-shore and shipbuilding applications • Addition of M6/W6 types • Addition of HCR high corrosion resistant shank materials (1.4529) • Addition of grating fasteners X-FCM-R and X-FCM-M • Addition of grounding application *) • Allowance of use on structural members requiring fatigue design
LR – Lloyds Register	Certificate: 03/00070(E1)	Unchanged Certificate: 03/00070(E1) (Nov. 2, 2009)	-
BV – Bureau Veritas	-	New Certificate: 23498/A0 BV (2011-04-19)	• Coverage of M8/M10/W10 types • Coverage of grating fasteners X-FCM-R and X-FCM-M
ICC-ES – International Code Council, Evaluation Service	ESR-2347	Updated Approval: ESR-2347 (Dec. 1, 2009, revised July 2011)	• Addition of M6/W6 types • Addition of HCR high corrosion resistant shank materials (1.4529)
UL – Underwriter Laboratories	E257069	E257069 (Nov. 7, 2011)	• Addition of M6/W6 types **)

*) grounding application as specified in chapter 2.6 of [1] in compliance with EN 60439-1, EN 60204-1, IEC 60947-7-2 and EN 50164-1)

**) grounding application as specified in UL approval in compliance with ANSI/UL467

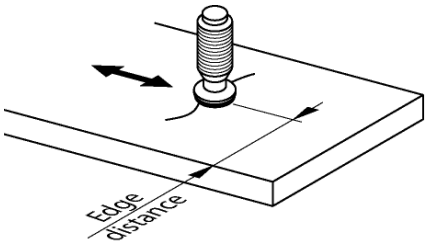
The addition of the new models into the Type Approvals of LR and BV is still pending.

2.2 Specifics on fatigue classification

2.2.1 Fatigue classification in compliance with Eurocode 3 (EN 1993-1-9)

Hilti ran a comprehensive fatigue test program in order to classify the constructional detail "*Structural steel base material with the Hilti powder-actuated fastener X-BT*" in compliance with the Eurocode 3 (EN 1993-1-9, [7]). A corresponding evaluation was made by *Prof. U. Kuhlmann* and *H.P. Günther* from the University of Stuttgart (Report No. 2010-57X [6]).

Table 7. Recommendation of fatigue detail category according to EN 1993-1-9:2005 [6, 1]

Detail category	Constructional detail	Description	Requirements
90 **100** **m = 5**		Hilti X-BT powder-actuated fasteners with pre-drilled hole in structural steel base material. Imperfect fastener installations as e.g. pulled-out fasteners or pre-drilled holes without fasteners are covered.	Δσ to be calculated by the gross cross-section. Installation, static loading and spacing of fasteners only in accordance with the requirements of the Hilti X-BT threaded fastener specification [1] Plate thickness t ≥ 8 mm Edge distance ≥ 15 mm

Category 90 corresponds with a standard category according to Table 7.1 of EN 1993-1-9 [7] with a slope m = 3 for cycles N ≤ 5 million cycles and a slope m = 5 for N > 5 million cycles (see Figure 8). Category 100 (m = 5) – with a constant slope m = 5 for N ≤ 100 million cycles – represents a possible, alternate option in compliance with the Eurocode 3. The latter is recommended in case of low amplitude high cycle fatigue loading. When using a fatigue assessment procedure based on a linear damage accumulation a mixture of both categories is not allowed.

The structural steel grades S235 up to S460 according to EN 10025-2, EN 10025-3, EN 10025-4 and EN 10225 are covered. These grades include thermo mechanically rolled fine grain steels.

The following Figure 7 shows a summary of all test data including the fatigue classification in keeping with the Eurocode 3.

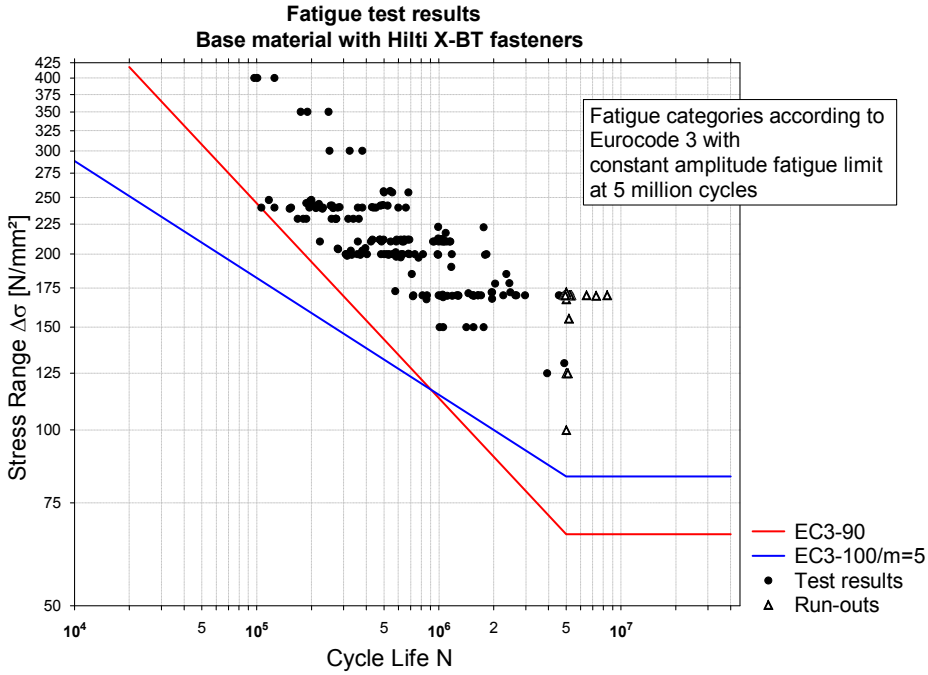


Figure 7. Test data compared with fatigue recommendation according to Eurocode 3 [6, 1]

2.2.2 Approved fatigue categories by GL (Germanischer Lloyd) and DNV (Det Norske Veritas)

Towers for wind turbines as well as the machinery for the wind turbines often are approved by classification societies like GL (Germanischer Lloyd) or DNV (Det Norske Veritas). Both classification societies recently also approved the fatigue category for the constructional detail *"Structural steel base material with Hilti powder-actuated fastener X-BT"*, see Table 8.

Table 8. Approved categories by GL and DNV

Classification Society	Hilti Type Approval Certificate	Fatigue standard	Detail category	Plate thickness	Thickness effect
GL	12272-10HH [4]	EC 3, EN 1993-1-9 [7]	90	8 mm ≤ t ≤ 60 mm	No. k_s = 1
DNV	S-6751 [5]	DNV RP-C203 [8]	C2	t ≥ 8 mm	for t ≥ 25 mm k = 0.15

Notes on GL Type Approval:

In order to allow clear use of the design category, GL proposed only to use the standard category 90 and omit the alternative option 100 with m = 5. GL also limited the use to the thickness range typically used in steel towers of wind turbines (t ≤ 60 mm). In case thicker plates are exceptionally used, acceptance is possible based on case specific consideration.

Note on DNV Type Approval:

Differing from the provisions in EN 1993-1-9 [7], the DNV fatigue standard DNV-RP-C203 [8] requires the consideration of the size effect (coefficient k = 0.15) for the detail category independent from the constructional detail. Therefore, for compliant design with DNV-RP-C203 a thickness effect is considered for thickness t ≥ 25 mm.

The fatigue strength curves are mathematically described by the following formula:

$$\log N = \log \bar{a} - m \cdot \log \Delta\sigma$$

The parameters m and $\log\bar{a}$ of the fatigue curves are summarized in the following tables 9 & 10. Table 11 gives also a comparison of the stress ranges Δσ for selected numbers of cycles and Figure 8 shows a graph with test data and the approved fatigue categories.

Table 9. Parameters of GL approved fatigue curve 90 according to EN 1993-1-9

Number of load cycles	m	$\log\bar{a}$
$N \le 5.10^6$	3	12.164
$5.10^6 \le N \le 10^8$	5	15.807

Table 10. Parameters of DNV approved fatigue curve C2 according to DNV-RP-C203

Number of load cycles	m	$\log\bar{a}$
$N \le 10^7$	3	12.301
$N > 10^7$	5	15.835

Table 11. Comparison of stress ranges

	Stress range Δσ [N/mm²]	
Number of load cycles N	GL EC3 - 90	DNV C2
1.10^5	244.3	271.4
1.10^6	113.4	126.0
2.10^6	90.0	100.0
5.10^6	66.3	73.7
1.10^7	57.7	58.5
1.10^8	36.4*)	36.9

*) corresponds with cut-off limit

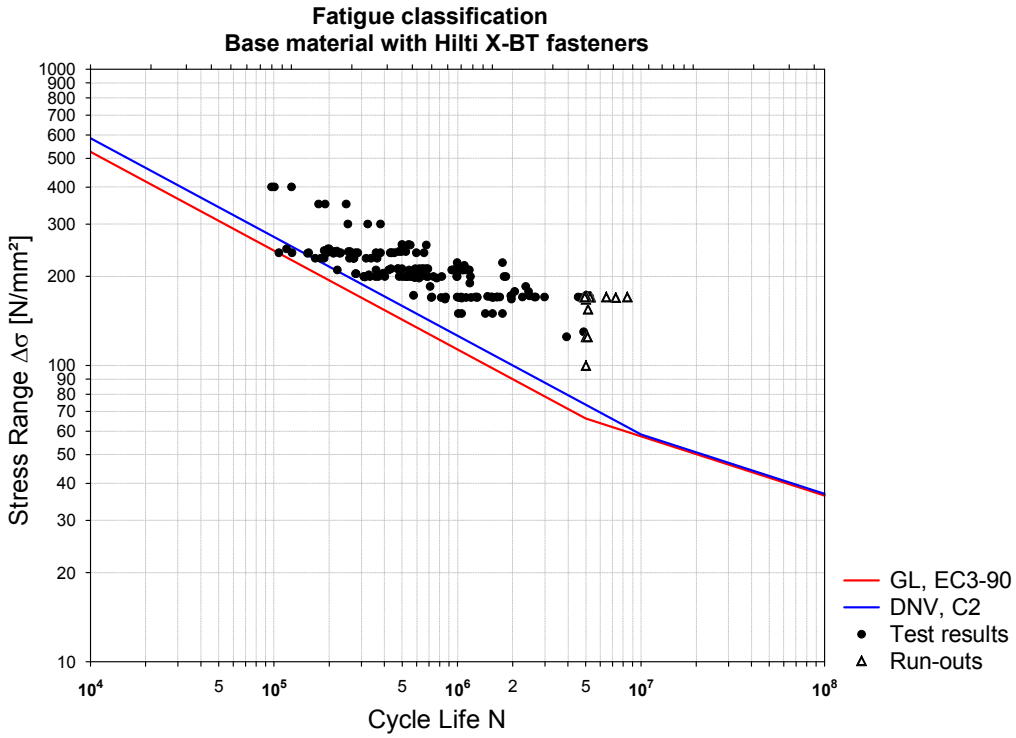


Figure 8. Test data compared with approved GL and DNV fatigue categories

3 Literature

[1] Hilti Corporation (2010): *Hilti X-BT Threaded Fastener Specification*, Edition December 2010

[2] Hilti Corporation (2009): *Hilti Direct Fastening Technology Manual*, Edition 11/2009

[3] Kuhlmann, U., Günther, H-P. (2011): *Hilti powder-actuated fastener X-BT in combination with the Hilti fastening tools DX 351 BT/BTG for the use in cast iron base material according to EN 1563,* Evaluation Report, Institut für Konstruktion und Entwurf, Stahl- Holz- und Verbundbau, University of Stuttgart, Report Nr. 2011-24X, Oct. 11, 2011.

[4] GL, Germanischer Lloyd (2011): *Approval Certificate: 12272-10HH, Mechanical Fastening Systems, Hilti X-BT stainless steel threaded fasteners,* Hamburg, 2011-11-04

[5] DNV, Det Norske Veritas (2011): *Type Approval Certificate No. S-6751, Structural Connecting Elements: X-BT threaded fasteners, Grating fasteners X-FCM-R, X-FCM-M,* Høvik, 2011-10-26

[6] Kuhlmann, U., Günther, H-P. (2010): *Fatigue strength of the constructional detail "Structural steel base material with the Hilti powder-actuated fastener X-BT" in compliance with Eurocode 3 Part 1-9 (EN 1993-1-9),* Institut für Konstruktion und Entwurf, Stahl- Holz- und Verbundbau, University of Stuttgart, Report Nr. 2010-57X, December 28, 2010

[7] EN 1993-1-9:2005 (2005): *Eurocode 3: Design of steel structures – Part 1-9: Fatigue,* European Standard, May 2005

[8] DNV-RP-C203, Det Norske Veritas (2010): *Recommended Practice: Fatigue design of offshore steel structures*, April 2010