HILTI BX 3-SCT TEST INSTRUCTIONS

Determination of the early strength of sprayed concrete with Hilti BX 3-SCT stud driving method

December 2021

PREFACE

This manual introduces and describes the new Hilti BX 3-SCT system which is intended to be used for the estimation of the compressive strength of young sprayed concrete.

The BX 3-SCT system replaces the current system Hilti DX 450-SCT which has been used for decades in this application. Other than the DX 450-SCT, the BX 3-SCT system uses the new battery-actuated fastening tool technology. Therefore, no powder cartridges are anymore required. Additional benefits of the BX 3-SCT system are that pulling of the studs is not required any longer and that the application scope of the procedure could be widened, now starting from a concrete strength of about 1 N/mm^2 upwards.

A new calibration curve was empirically evaluated for the BX 3-SCT. The respective experimental investigations were performed at the Faculty of Civil Engineering at OTH-Regensburg (Ostbayerische Technische Hochschule Regensburg, Regensburg University of Applied Sciences) in Germany. These test instructions are compiled by Hilti Corporation in cooperation with Prof. Charlotte Thiel and Prof. Wolfgang Kusterle, both from OTH-Regensburg.

Note on DX 450-SCT system: Hilti will stop selling new DX 450-SCT tools but will of course further maintain repair services for the existing tools in the market. Furthermore, studs and cartridges required for the DX 450-SCT stud driving method will be continued to be supplied in order to use the DX 450-SCT method with the tool population existing in the market.

December 2021

CONTENT

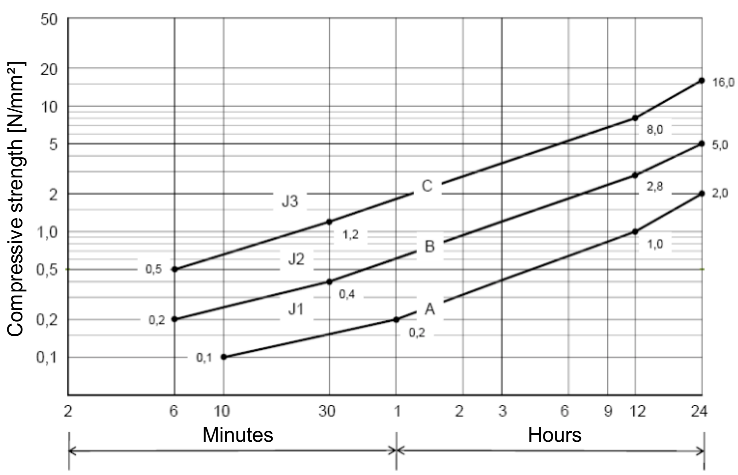
1 EARLY STRENGTH OF SPRAYED CONCRETE

1.1 Definitions and early strength classes

Sprayed concrete (SpC)	Concrete produced with basic mix and projected pneumatically at high velocity from a nozzle into place to produce a dense homogeneous mass by its own momentum.
Young sprayed concrete	Sprayed concrete up to an age of 24 hours.
Early strength	Compressive strength of young sprayed concrete. The requirements on the early strength are specified by early strength classes J_1, J_2 and J_3.

In tunnel construction often thick layers of sprayed concrete have to be placed overhead or to vertical walls. Therefore, sprayed concrete with a fast setting and high early strength is required. To achieve these properties, special binders or typically cement based binders – often combined with supplementary cementitious materials – are used together with accelerators.

Depending on the tunneling method and the rock class different early strength classes of the sprayed concrete are required. For safety reasons early strength verification during construction is necessary by a sufficiently accurate testing method. Common early strength classes J1 to J3 are defined in the ÖBV guideline[1) "Sprayed Concrete" [1] as well as in EN 14487-1 [2].



between A and B:	Class J_1
between B and C:	Class J_2
above C:	Class J_3

Note: Over the past years, this diagram was slightly modified. Use the diagram, which was defined by contract for the specific construction.

Figure 1: Early strength classes of young sprayed concrete [1]

1) ÖBV – Österreichische Bautechnik Vereinigung (Austrian Society for Construction Technology), www.bautechnik.pro

1.2 Early strength test methods

A direct measurement of the early strength with test specimen is not possible, as cubes or other test shapes cannot be sprayed uniformly. Due to the rough tunnel environment only robust measuring methods are applicable. The following requirements need to be met: Easy to use, fast, subsequent use everywhere in the tunnel, allowing measurement on rough surface, not affected by fiber reinforcement.

Two measuring methods have been generally accepted:

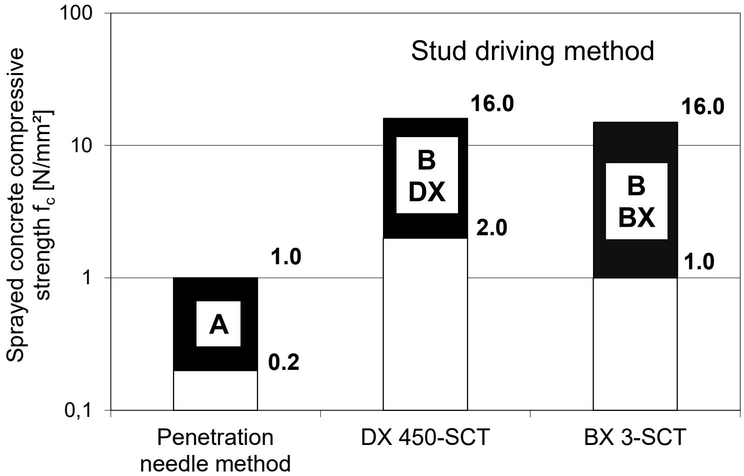
- Penetration needle method
- Stud driving method

Both use the indirect approach of driving a thin penetration body into the concrete and have been successfully proven on tunnel job-sites all over the world.

The "Penetration needle method" utilizes a needle (Ø 3 ± 0.1 mm) which is driven by means of a penetrometer into the young sprayed concrete. The force needed to drive the needle 15 ± 2 mm deep into the sprayed concrete is recorded. It is applicable for the initial early strength of up to about 1.0 N/mm^2.

The "Stud driving method" uses threaded studs which are driven into the concrete by means of a direct fastening tool with a defined driving energy. The "Stud driving method" was developed 1984 by Prof. Dr. Wolfgang Kusterle at the University of Innsbruck, Austria [5]. The method Hilti DX 450-SCT is included since the 1990´ties in the ÖBV guideline "Sprayed Concrete" [1]. The general "Stud driving method" is further covered as "Method B" by EN 14488-2 since 2006 [4].

Figure 2 shows the range of application of the "Penetration needle method", the current DX 450-SCT as well the new BX 3-SCT stud driving method.



Method A
Penetration needle Ø 3 mm

Method B (DX)
Stud driving method with powder-actuated system Hilti DX 450-SCT: Green cartridge 6.8/11M and threaded studs with a diameter of 3.7 mm

Method B (BX)
Stud driving method with new battery-actuated system Hilti BX 3-SCT: Threaded studs with a diameter of 3.7 mm

Figure 2: Measurement methods and sprayed concrete strength range

In case of the Hilti DX 450-SCT Green cartridge method the studs are driven into the concrete and are subsequently pulled out from it. It is applicable beginning from concrete strength of about 2 N/mm^2 up to 16 N/mm^2. The relevant test parameter is the ratio of pullout force to the fastener embedment. A historical review of the different DX 450 test method is provided in [6].

In case of the new Hilti BX 3-SCT method the studs are only driven into the concrete and no pullout from the concrete is further required. It is applicable beginning from concrete strength of about 1 N/mm^2 up to 16 N/mm^2. The relevant test parameter is the fastener embedment[1)].

Beyond a concrete strength >10 N/mm^2 testing of drill cores taken from the sprayed concrete is further recommended.

1.3 Frequency of testing

As described above the “Stud driving method” is covered by several specifications, such as the ÖBV guideline “Sprayed Concrete” [1]. These guidelines also address the required level of conformity assessment for sprayed concrete including specifically the compliance check with the specified early strength J-class.

The frequency of sprayed concrete testing depends on the specified inspection category UEK I, II or III, in detail see [1]:

Test parameter	Pre-construction test	Conformity assessment	Inspection category UEK I	Inspection category UEK II	Inspection category UEK III	Identity verification
Early strength class	x	x	every 2 months or every 5000 m^2	monthly or every 2500 m^2	2 per month or every 1250 m^2	every 20 000 m^2

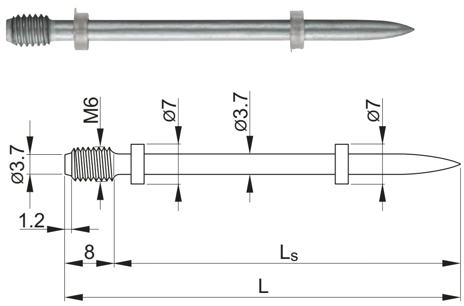
1) The current test program at OTH-Regensburg [7] also included the investigation of the early strength correlation with the force to embedment ratio of the studs. However, results showed that for the BX 3-SCT system the consideration of the embedment alone gives better correlation, especially in the range of low early strength (1 to 4 N/mm^2).

2 BX 3-SCT STUD DRIVING METHOD

2.1 Test equipment

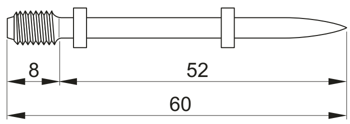
Battery-actuated tool Hilti BX 3-SCT

Carbon steel zinc plated studs with a shank diameter of 3.7 mm

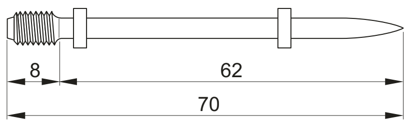


Ls ... shank length
L ... total stud length

X-M6-8-52 DP7 SCT B3



X-M6-8-62 DP7 SCT B3



X-M6-8-87 DP7 SCT B3

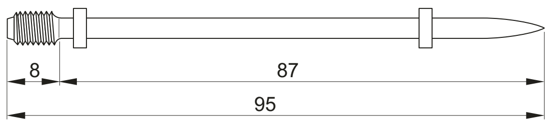


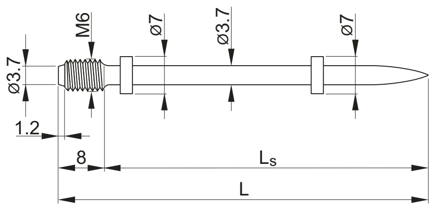
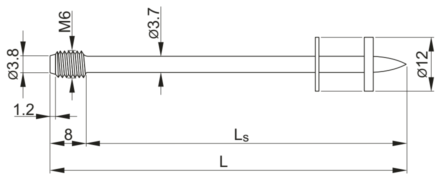
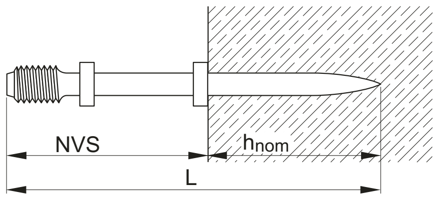
Figure 3: BX 3-SCT test equipment

Notes on stud designation:

M6-8 ...	M6 thread with a thread length of 8 mm
52, 62 or 87 ...	Shank length L_s of the respective fastener
60, 70 or 95 ...	Total length L of the respective fastener
DP7 ...	Double plastic washers with an outer diameter of 7 mm
SCT ...	Studs intended for Sprayed Concrete Testing
B3 ...	Studs intended to be used with battery-actuated BX 3-SCT tool

A survey on the order information is given in Appendix 5.

2.2 BX 3-SCT features and comparison with DX 450-SCT

Features	Battery-actuated BX 3-SCT	Powder-actuated DX 450-SCT
Fastening principle & driving energy	Direct fastening tool with integrated captive piston, which drives the stud into the concrete. Driving energy: Mechanical energy loaded by an accumulator. No powder-cartridge is needed.	Also contains a captive piston, but the driving energy comes from the combustion of a powder cartridge.
Tool energy setting[1]	Not required. The tool energy is constant and cannot be adjusted.	Is required. The operator needs to use the correct cartridge and needs to set the correct driving energy on the tool.
Studs[2]	M6 studs with a shank diameter of 3.7 mm and 3 shank lengths L_s of 52, 62 and 87 mm.  2 plastic washers with 7 mm diameter	M6 studs with a shank diameter of 3.7 mm and 3 shank lengths L_s of 52, 72 and 95 mm.  1 plastic and 1 metal washer with 12 mm diameter
Calibration parameter	The calibration is done by means of the fastener embedment h_{nom} [mm].  No pullout testing is required with the BX 3-SCT stud driving method.	The calibration is done by means of the ratio of pullout force to fastener embedment N_u/h_{nom} [N/mm], see in detail [1], [4], [5], [6].
Calibration curves	As the driving energy of the BX 3-SCT depends on the stud length, 2 separate calibration curves were established: Curve A: X-M6-8-87 DP7 SCT B3 Curve B: X-M6-8-52 DP7 SCT B3 and X-M6-8-62 DP7 SCT B3	One calibration applicable for all stud length.

1) Tool energy: BX 3-SCT: 77 ± 7 J, DX 450-SCT: 96 ± 8 J

2) Use of DX 450-SCT studs with the BX 3-SCT is neither allowed nor practically possible, as the fasteners are not held within the fastener guide of the BX 3-SCT tool. Using BX 3-SCT studs with the DX 450-SCT is also not allowed and also practically not possible as these 7 mm diameter studs are not held in the DX 450-SCT tool as well.

2.3 Steps of operation and strength estimation

Before starting:
Before initial tool operation first read the BX 3-SCT tool operating instructions as prerequisite for safe, trouble-fee handling and product use. Observe all safety instructions and warnings given in the operating instructions which are supplied together with each tool.

1. Select the right stud for the expected concrete strength.

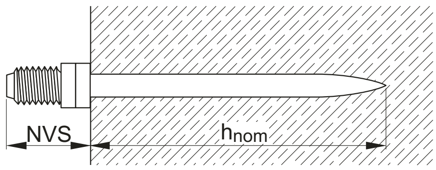
Stud type	Early strength range f_c [1)]	Remarks
X-M6-8-87 DP7 SCT B3	1 to 4 N/mm²	Not calibrated beyond 4 N/mm²
X-M6-8-52 DP7 SCT B3 X-M6-8-62 DP7 SCT B3	2 to 16 N/mm²	Whenever possible, the shorter stud X-M6-8-52 DP7 SCT B3 should be used. Only when the 52-stud is too short in the lower concrete strength range, the longer X-M6-8-62 DP7 SCT B3 is to be used.

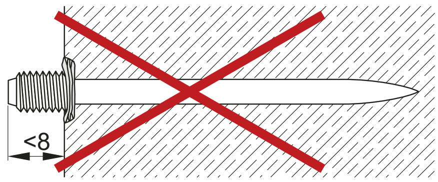
[1)] 150 mm cube strength

In general the shortest possible stud should always be used.

The following stand-off and embedment provisions are to be observed:

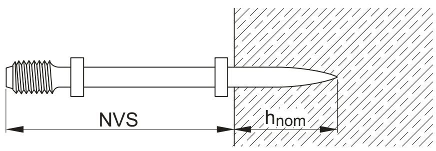
Stand-off
NVS ≥ 8 mm

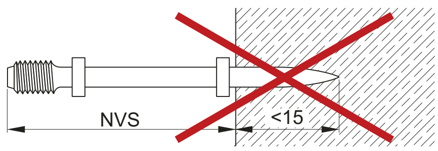




In case NVS is less than 8 mm and when already using the longest stud X-M6-8-87 DP7 SCT B3, the concrete is still too soft for the BX 3-SCT test method.

Fastener embedment
h_{nom} ≥ 15 mm



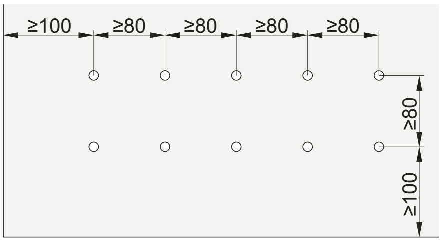


In case the embedment h_{nom} of individual fasteners is less than 15 mm, the concrete is already too hard for the BX 3-SCT test method.
The minimum average embedment of a series of 10 studs should amount to 20 mm, else the concrete is too hard for the BX 3-SCT test method.

2. Drive 10 studs with the battery-actuated BX 3-SCT fastening tool observing the tool operating instructions.

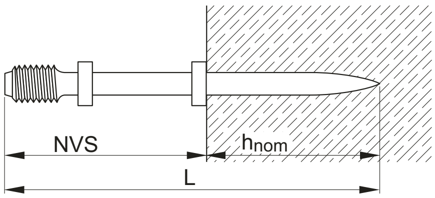
   The studs are manually fed into the tubular fastener guide as shown below. The stud is sufficiently inserted, if the plastic washer close to it´s tip is held within the fastener guide of the tool[1]. When the tool is compressed against the concrete surface, the fastener will completely slip into the tubular fastener guide.

   The minimum center-to-center spacing must be at least 80 mm. The edge distance must be at least 100 mm.



   Note:
   Edge distance 100 mm relevant when method is applied with spraying panels.

3. Measure and record stand-off NVS above concrete surface of every stud.



4. Calculate the fastener embedment h_{nom} of every single threaded stud.

	Stud type	Total length L [mm]
h_{nom} = L – NVS	X-M6-8-52 DP7 SCT B3	60
	X-M6-8-62 DP7 SCT B3	70
	X-M6-8-87 DP7 SCT B3	95

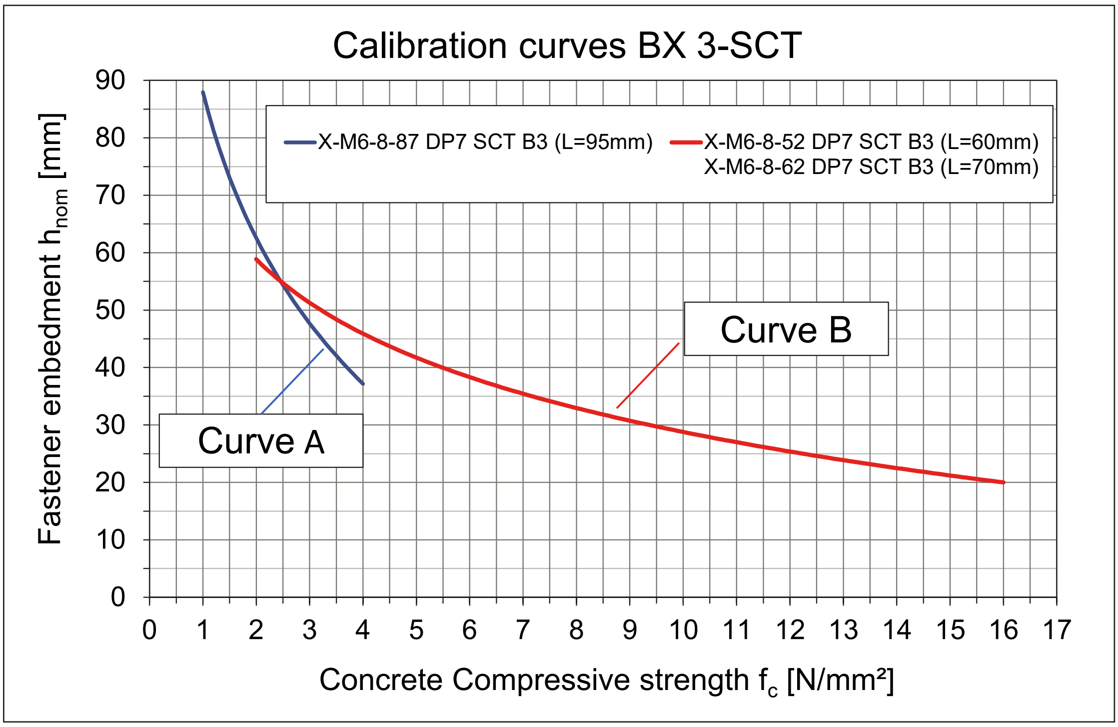
[1] The plastic washers are designed in such a way that they clamp inside the fastener guide and prevent the studs from falling out of the guide. The studs may also be manually fed fully into the fastener guide with tip of the stud flush with the front part of the fastener guide.

5. Calculate the mean fastener embedment h_{nom} for all 10 studs of the test series.

6. Estimate the sprayed concrete early strength using the below calibration diagram or calibration formula. As the driving energy of the BX 3-SCT depends on the stud length, 2 separate calibration curves A and B were established:

Stud	Strength range f_c	Calibration curve	Calibration formula
X-M6-8-87 DP7 SCT B3	**1 to 4 N/mm²**	**A**	$f_c = e^{-\frac{h_{nom}-87.93}{36.62}}$
X-M6-8-52 DP7 SCT B3 X-M6-8-62 DP7 SCT B3	**2 to 16 N/mm²**	**B**	$f_c = e^{-\frac{h_{nom}-71.82}{18.69}}$

h_{nom} ... mean fastener embedment in [mm] from series with 10 samples
f_c ... estimated early cube strength (150 mm) in [N/mm²]



The calibration curves consider the concrete mixes tested in [7], a survey on the respective mixes is given in section 2.4 and Appendix 4.

The non-linear curves represent the mean value of the test results of all concrete mixes.

2.4 Survey of concrete mixes used for calibration

For the experimental evaluation of the calibration [7], 6 different concrete mixes were used which are typical for uses in sprayed concrete works[1]:

- Aggregates: Angular or round grain of standard hardness (mixed dolomitic limestone) with a maximum aggregate size of 8 mm.
- Grading curve B8. Some mixtures contained more fine grain and some contained less fine grain than the nominal B8 grading curve.
- The binder content varied in the range from 400 to 480 kg/m^3.
- The water/binder ratio varied in the range from 0.45 to 0.62.
- The air void content varied in a range from 1.2 to 3.9 %.

A summary of the different concrete mixes is given in Appendix 4.

The calibration curves are well suited for mixes and aggregates commonly used in Central Europe. In case of deviating mixes – especially with respect to the Mohs hardness of the aggregates, e.g. quartzite with Mohs hardness 7 – it is recommended to develop a new calibration curve on site. The corresponding procedure is also shortly described in the ÖBV Sprayed Concrete Guideline as follows:

“Base mixes without accelerator should be used for the calibration. Therefore, the prescription of the test mix needs to consider the losses due to rebound (higher binder content, finer grading line). The mix is placed into the test moulds, compacted and stored protected from evaporation. The compressive strength of the cubes (or cylinders) will be evaluated after certain time in compliance with recognized test procedures. Removal of the specimen formwork is done shortly before the test. The use of appropriate test equipment for the measurement of small loads is required.

In parallel stud driving tests according to the respective test procedure will be executed. These are done on separately produced plates of about the same cubature, but with a thickness of 10 cm. The temperature development in the cubes and the plates should be similar, in order to test with the same grade of hydration or with the same maturity. The plates remain in the form during the stud driving test and need to be supported firmly. Testing shall be executed promptly with the reference cube tests. With the results of both tests, a calibration curve is established by means of linear regression analysis. The correlation coefficient R should be > 0.85. Extrapolations are not permissible.”

1) Though a variety of mixes was considered in the test program, the characteristics of the sprayed concrete actually used might deviate and limit the general applicability of the calibration. Therefore, Hilti recommends initial project-specific check of the calibration curve.

3 LITERATURE AND APPENDICES

3.1 Literature and Specifications

[1] ÖBV Guideline Sprayed Concrete (2013), Österreichische Bautechnik Vereinigung, Issue April 2013.

[2] EN 14487-1:2005: Sprayed concrete – Part 1: Definitions, specifications and conformity.

[3] EN 14487-2:2006: Sprayed concrete – Part 2: Execution.

[4] EN 14488-2:2006: Testing sprayed concrete – Part 2: Compressive strength of young sprayed concrete.

[5] Kusterle, W. (1984): Ein kombiniertes Verfahren zur Beurteilung der Frühfestigkeit von Spritzbeton ("A combined method for determining the early strength of sprayed concrete"). Beton- und Stahlbetonbau, Heft 9/1984 (in German).

[6] Hilti (2011): Determination of the early strength of sprayed concrete with stud driving method Hilti DX 450-SCT, December 2011.

[7] Hechenbichler, J., Kuyten, L., Thiel, C. (2021): Hilti BX 3-SCT: Erstellung einer Kalibrierung für die Frühfestigkeits-bestimmung von Spritzbeton ("Hilti BX 3-SCT: Generation of a calibration for the determination of the compressive strength of young sprayed concrete"), OTH-Regensburg, Ostbayerische Technische Hochschule Regensburg, Faculty of Civil Engineering, 22. November 2021 (in German).

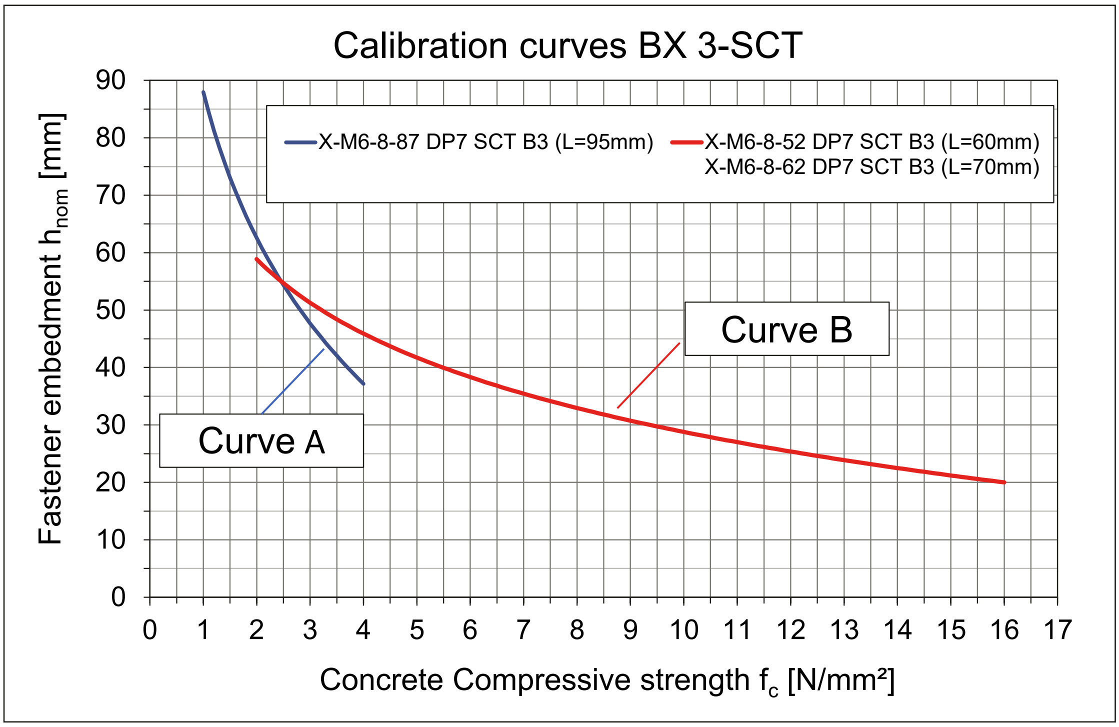
3.2 Appendices

Appendix 1: BX 3-SCT calibration curve and formula
Appendix 2: Calibration curve A: Example of test record form and concrete estimation
Appendix 3: Calibration curve B: Example of test record form and concrete estimation
Appendix 4: Mix design for calibration tests
Appendix 5: Order information

APPENDIX 1: BX 3-SCT CALIBRATION CURVES

Stud	Strength range f_c	Calibration curve	Calibration formula
X-M6-8-87 DP7 SCT B3	**1 to 4 N/mm²**	**A**	$f_c = e^{-\frac{h_{nom}-87.93}{36.62}}$
X-M6-8-52 DP7 SCT B3 X-M6-8-62 DP7 SCT B3	**2 to 16 N/mm²**	**B**	$f_c = e^{-\frac{h_{nom}-71.82}{18.69}}$

The coefficient of correlation amounts to R = 0.92 for both calibration curves.

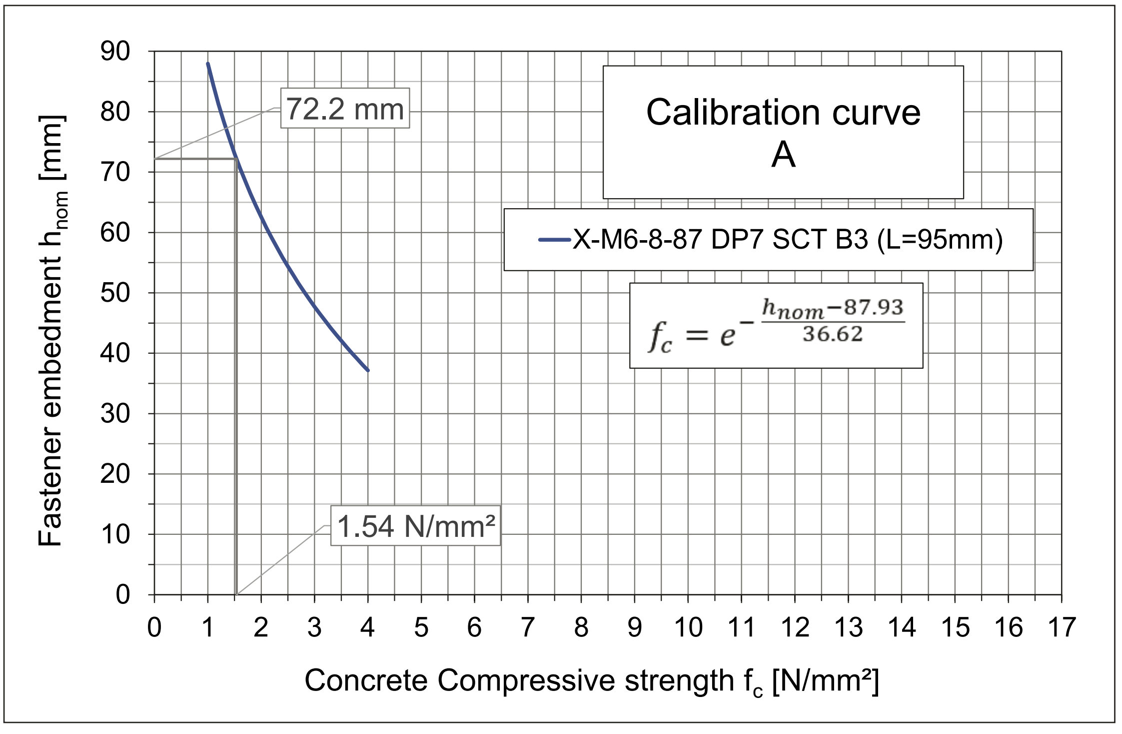


APPENDIX 2: EXAMPLE CALIBRATION CURVE A

Remark: Forms used in practice need to include information on project, location, test engineer, concrete mix, time of spraying and time of testing.

Tool	Tool serial number	Stud type	Total stud length L [mm]
BX 3-SCT	1000	X-M6-8-87 DP7 SCT B3	95

Stud #	Stand-off NVS [mm]	Embedment depth h_{nom} [mm]	Mean embedment depth h_{nom} [mm]	Concrete strength f_c [N/mm²]
1	25	70	72.2	1.54
2	26	69		
3	22	73		
4	27	68		
5	20	75		
6	21	74		
7	26	69		
8	27	68		
9	15	80		
10	19	76		

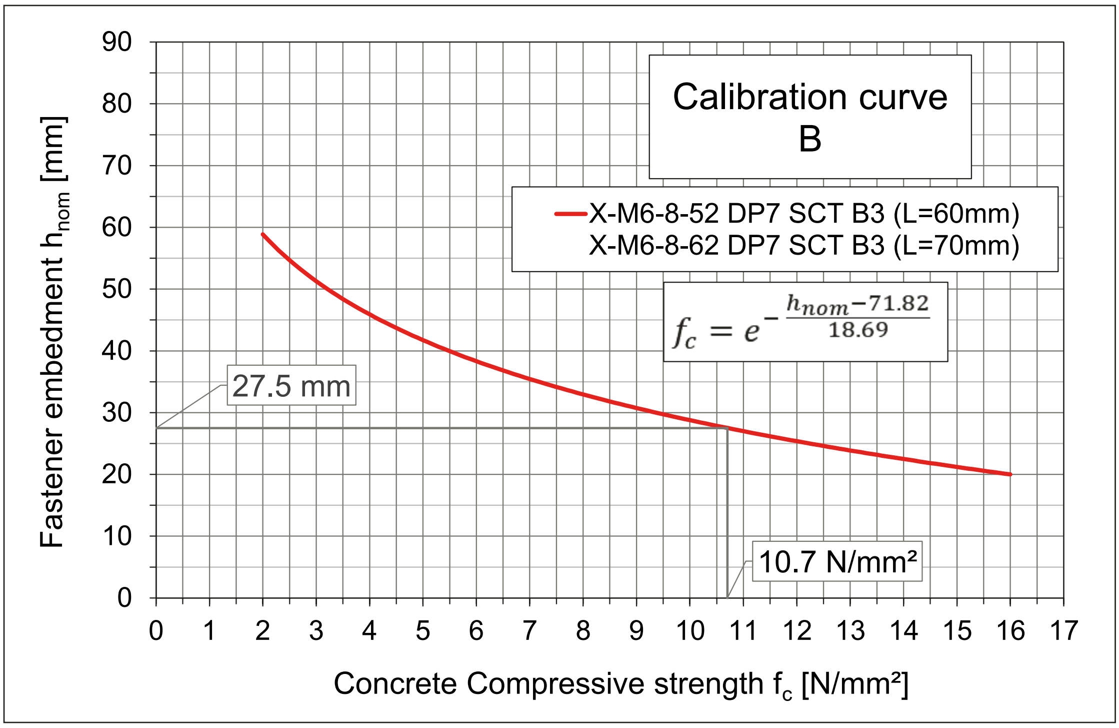


APPENDIX 3: EXAMPLE CALIBRATION CURVE B

Remark: Forms used in practice need to include information on project, location, test engineer, concrete mix, time of spraying and time of testing.

Tool	Tool serial number	Stud type	Total stud length L [mm]
BX 3-SCT	1000	X-M6-8-52 DP7 SCT B3	60

Stud #	Stand-off NVS [mm]	Embedment depth h_{nom} [mm]	Mean embedment depth h_{nom} [mm]	Concrete strength f_c [N/mm²]
1	34	26	**27.5**	**10.7**
2	35	25		
3	29	31		
4	31	29		
5	33	27		
6	35	25		
7	29	31		
8	34	26		
9	33	27		
10	32	28		

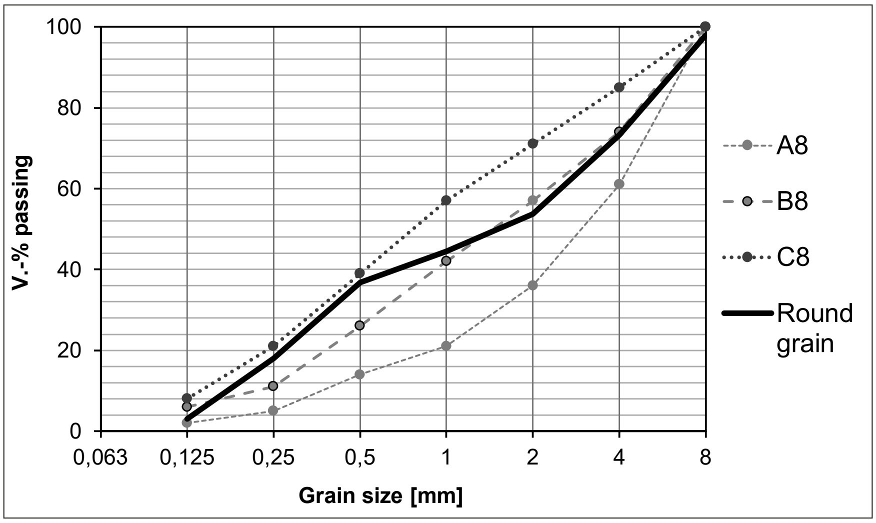


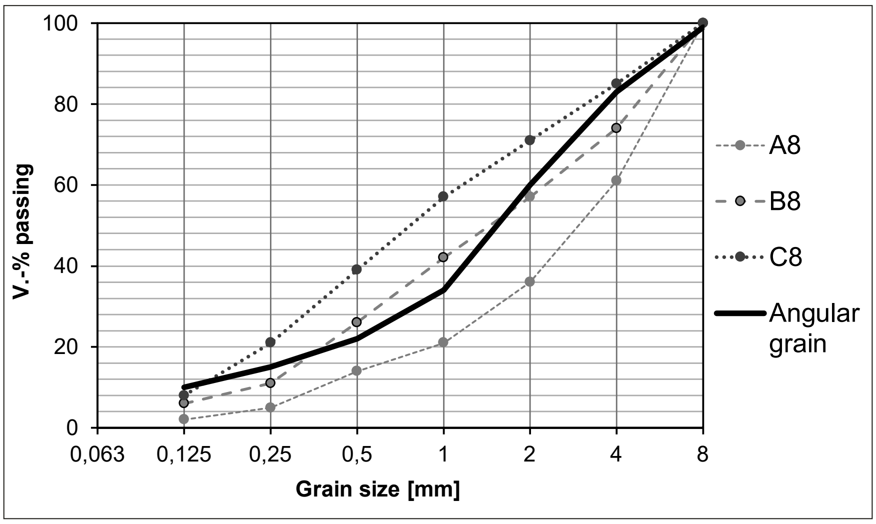
APPENDIX 4: MIX DESIGN FOR CALIBRATION TESTS

Concrete Mix	Aggregates[1]	Max. grain size [mm]	binder content [kg/m³]	cement[2] content [kg/m³]	additives[3] [kg/m³]	w/b ratio
1	round	8	**420**	**280**	**140**	0.46
2	round	8	**460**	**307**	**153**	0.46
3	round	8	**480**	**320**	**160**	0.46
4	round	8	**460**	**307**	**153**	0.51
5	angular	8	**460**	**307**	**153**	0.46
7	round	8	**400**	**267**	**133**	0.62

[1] Petrographic analysis: Mixed dolomitic limestone, standard hardness
[2] Cement: CEM I 52.5 R
[3] Additives: A mixture of slag, flyash and limestone powder
Admixtures: Water reducing agents and air entraining agents were used for achieving a spread table flow of 500 to 600 mm and 3 % entrained air.

Aggregate analysis





APPENDIX 5: ORDER INFORMATION

Ordering designation	Item number	
Sprayed concrete testing tool		
BX 3-SCT (02)	2330184	
	2346819	for USA and Canada, only
B22 22V Li-ion batteries, recommended		
B22 2.6 22V Li-ion battery	2136393	
B22 2.6 22V Li-ion battery	2136395	for USA and Canada, only
Chargers for Hilti Li-ion batteries		
Item numbers of chargers C4/36 may vary between the local markets. Please consult the local Hilti website for ordering details in the respective country.		
Batteries and chargers are to be ordered separately.		
Consumables and spare parts		
X-M6-8-52 DP7 SCT B3 threaded studs (100 pcs/box)	2323247	
X-M6-8-62 DP7 SCT B3 threaded studs (100 pcs/box)	2323246	
X-M6-8-87 DP7 SCT B3 threaded studs (100 pcs/box)	2323248	
X-FG B3-SCT 02 fastener guide	2337405	

Hilti Corporation
9494 Schaan, Liechtenstein
P +423-234 2965

www.facebook.com/hiltigroup
www.hilti.group