Determination of the early strength of sprayed concrete with stud driving method Hilti DX 450-SCT

Operating Instructions

December 2011

Preface

These operating instructions were compiled by the Business Unit Direct Fastening of Hilti Corporation in co-operation with Prof. Dipl.-Ing. Dr. Wolfgang Kusterle of the HS-Regensburg.

These instructions are an update of the instructions dated with January 2009. The update covers primarily the reference to the current guideline „Spritzbeton" ("Sprayed Concrete") of the ÖVBB (Austrian Society for Concrete- and Construction Technology) from December 2009.

Schaan, December 20, 2011

Content

Appendices

1 Introduction

These operating instructions are based on EN 14488-2, edition 11/06 and the guideline „Sprayed Concrete“, December 2009. This guideline is published by the „Österreichischen Vereinigung für Beton- und Bautechnik“ (ÖVBB) („Austrian Society for Concrete and Construction Technology“).

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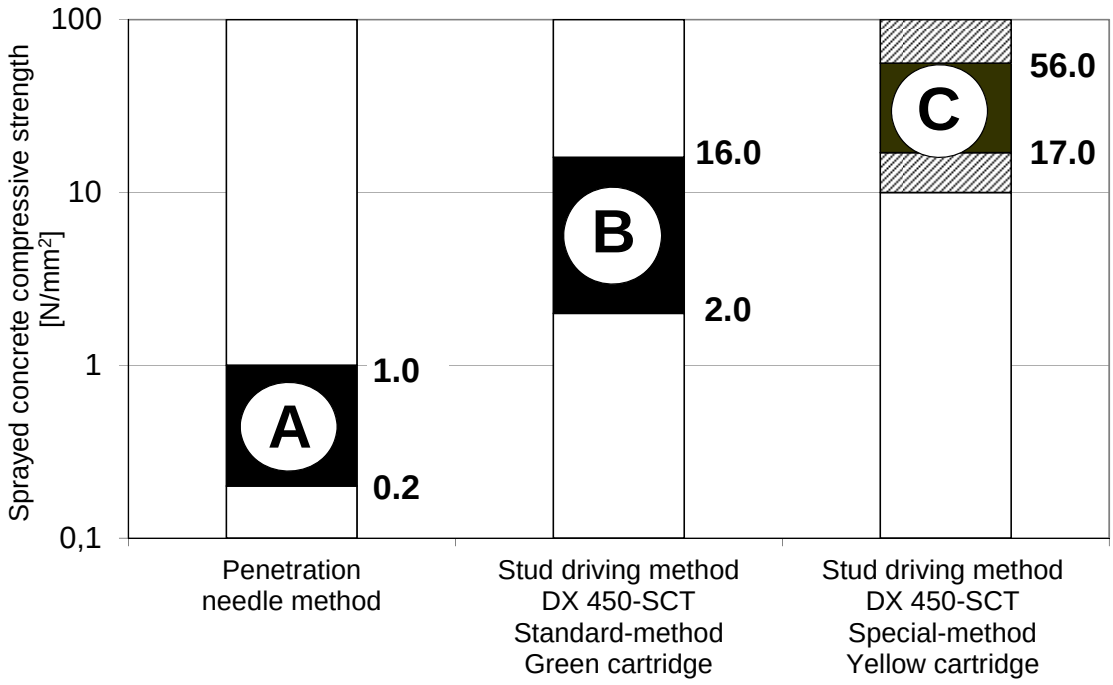
For the time being the current 2009-edition of the guideline is only available in German. An English translation of this 2009-edition is expected by middle of 2012. (Note, that English translations of previous editions, see chapter 2.1, of the guideline are available and can be ordered via the ÖVBB website.)

The described stud driving method for determination of the compressive strength was originally developed by Prof. Dipl.-Ing. Dr. Wolfgang Kusterle at the University of Innsbruck, Austria.

The following graph (according to the guideline „Sprayed Concrete“, edition 2006) shows the range of application of various test methods.



A - Penetration needle ϕ 3 mm
B - Stud driving method with Hilti **DX 450-SCT** and Green cartridge (threaded studs with a diameter of 3.7 mm): **Standard-method** for the strength range from 2.0 und 16.0 N/mm²
C1 - Concrete cores for strength > 10.0 N/mm²
C2 - Stud driving method with Hilti **DX 450-SCT** und Yellow cartridge (threaded studs with a diameter of 3.7 mm): Special-method for the strength range from 17.0 to 56.0 N/mm²

Since 2009 the formerly used tool DX 450 L will be distributed with the new designation **DX 450-SCT**. **SCT** stands for **Sprayed Concrete Testing**.

The tool DX 450-SCT will be delivered – ready assembled with the required test equipment (base plate, fastener guide, piston) – in a Hilti tool-box (item number: 233871). The tool-box offers additional space for the required pullout test device (see chapter 3.2. and appendix 7).

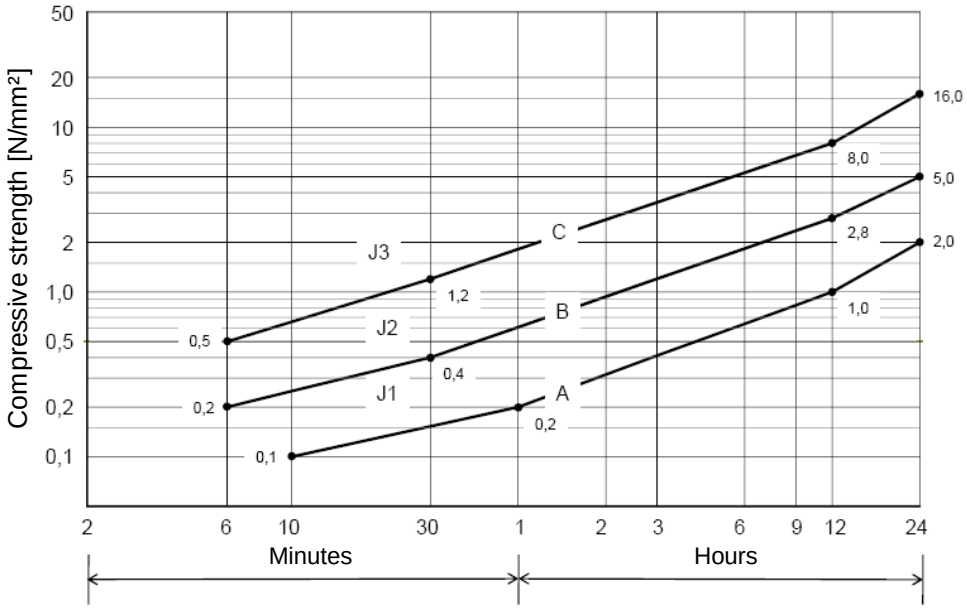
To order equipment or for further advice, contact the Hilti marketing organization in your country. Contacts are given on the Hilti web-site ***www.hilti.com***.

2 Early strength of sprayed concrete

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 a high early strength is required. To achieve these properties, special binders or typically binders (e.g. cements) in combination with accelerators are used.

Safety requirements demand a sufficiently accurate knowledge of the actual concrete strength. Different requirements on the early strength development depend on the use of the sprayed concrete. The strength development also has to be proven during construction. Common early strength classes are defined in EN 14487-1 and the ÖVBB guideline “Sprayed Concrete”, Edition 12/2009 (see graph below).

Early strength classes of young sprayed concrete



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

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

The following paragraphs provide a translation of an extract taken from the ÖVBB-guideline „Sprayed Concrete“ (current edition 12/2009) and give a description of the early strength classes as well as the required tests:

> *„An adequate development of strength during the first few minutes is a precondition for overhead placing (strength after 2 minutes 0.1 – 0.2 MPa). The development of strength during the first two minutes also has a major influence on the extent of dust formation and rebound. If strength builds up too fast, the sprayed concrete will harden instantly after being jetted onto the substrate, which prevents proper embedding of the coarse-grained particles of the subsequent shot. Hence, to keep dust formation and rebound within acceptable limits, the strength measured after 2 minutes under normal conditions should not exceed 0.2 MPa.*
>
> ***J_1** sprayed concrete is suited for the placing of thin layers on a dry substrate without special load-bearing requirements and offers the advantage of low dust formation and rebound.*
>
> *If sprayed concrete is to be placed in thick layers (including overhead) at a high delivery rate, strength development according to **J_2** is required. The same applies to locations with water seepage and applications involving immediate loading due to subsequent operations (e.g. drilling of anchor holes, driving of steel lagging, vibrations due to blasting).*

J_2 also have to be met in the case of rapid load build-up due to rock pressure, earth pressure or gravity loads. The specification of the range required also depends on the degree of utilization of the fresh sprayed concrete.

For reasons of increased dust formation and rebound, J_3 sprayed concrete should only be specified under special circumstances (e.g. strong ingress of water, load-bearing requirements, fast rate of advance).

The development of strength of young sprayed concrete is determined by the described specified test methods. Testing and measuring have to be timed during the period from 2 minutes to 3 hours in accordance with the build-up of strength in the sprayed concrete so as to obtain as continuous a graph of strength development as possible (the timing shown in the diagram serving as a guideline). It should be noted, though, that strength values between 1.0 and 2.0 N/mm² cannot be measured on account of the test methods required. Based on the results of the preconstruction tests, the test times should be agreed between the partners in such a way, that measurements between 1.0 and 2.0 N/mm² are not required. In all cases the development of sprayed concrete strength has to be demonstrated from 6 minutes on up to a strength of 1.0 N/mm². Moreover, at least one value has to be obtained for the period of 4 to 9 hours (in the measuring range of Procedure B) and 24 hours after placing. Evidence of strength development between 9 and 24 hours is only required in case of specific specification of a test time (e.g. J_2 and after 12 h: 5.0 N/mm²)." [English translation of extract of ÖVBB-Guideline „Sprayed Concrete", edition 12/2009]

2.1 Specifications and complementing literature

Specifications

- ÖVBB-Guideline Sprayed Concrete, Edition 1999
- ÖVBB-Guideline Sprayed Concrete, Edition 2006
- ÖVBB-Guideline "Spritzbeton", Edition 12/2009 (English translation "Sprayed Concrete" in preparation)
- ÖNORM EN 14488-2: Prüfung von Spritzbeton – Teil 2: Druckfestigkeit von jungem Spritzbeton (*Testing sprayed concrete – Part 2: Compressive strength of young sprayed concrete*), Edition 11/2006
- ÖNORM EN 14487-1: Spritzbeton – Teil 1: Begriffe, Festlegungen und Konformität (Sprayed concrete – Part 1: Definitions, specifications and conformity), Edition 05/2006
- ÖNORM EN 14487-2: Spritzbeton – Teil 2: Ausführung (Sprayed concrete – Part 2: Execution), Edition 01/2007

Remark: The stud driving standard method is included in each edition, the special methods are only covered in some editions, a survey is given in chapter 2.4.

Complementing literature

- Kusterle, W.: Optimierung der Komponenten für Spritzbeton *(„Optimization of components of sprayed concrete").*
  Dissertation Universität Innsbruck, 1984, (in German)
- Kusterle, W.: 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)
- Testor, M.; Kusterle, W.: Ermittlung von Spritzbetondruckfestigkeiten, Modifiziertes Setzbolzenverfahren und Abhängigkeit der Druckfestigkeit von der Probekörpergeometrie *(„Determination of sprayed concrete strength, modified stud driving method and dependence of strength on the specimen shape").*
  Zement + Beton 3/ 1998, (in German)
- Leitner, Ch.: Indirekte Verfahren zur Druckfestigkeitsbestimmung von Spritzbetonen *(„Indirect methods of determination of the strength of sprayed concrete").*
  Diplomarbeit Universität Innsbruck, 1998, (in German).

2.2 Definitions

Early strength	Compressive strength of young sprayed concrete. The requirements on the early strength are specified by early strength classes (classes J_1, J_2, J_3).
Young sprayed concrete	Sprayed concrete up to an age of 24 hours.
Sprayed concrete (SpC)	Concrete projected into place at high velocity – placing of base mix, eventually water and/or accelerators – and compacted by its own momentum.
Penetration needle method	Method utilizing a needle (∅ 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 into the sprayed concrete is recorded.
Stud driving method	Threaded studs are driven into the concrete with a defined energy using a powder-actuated tool. The studs are subsequently pulled out from the concrete by means of tensile tester measuring the pullout force.

2.3 Measuring principles

A direct measurement of the early strength with test specimen is not possible, as cubes or other test shapes cannot be sprayed unerring. 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. Both use the indirect approach of driving a thin penetration body into the concrete.

The **Penetration needle method** records the force needed to drive a needle 15 mm deep into the sprayed concrete. It is applicable for the initial early strength of up to about 1.0 N/mm².

The **Stud driving method** uses powder-actuated threaded studs, which are driven into the concrete with a defined driving energy. Subsequently the studs are pulled out from the concrete with measurement of the pullout force. The stud driving method is applicable beginning from concrete strength of about 2 N/mm². The relevant test parameter is the ratio of pullout force to depth of penetration.

Besides the Standard-method (Hilti DX 450-SCT with Green cartridge) also other procedures with a different measuring range (1 to 8 MPa, 17 to 56 MPa) were calibrated. Generally only the Standard-method should be used, in order to avoid confusion on the job-site.

Both the Penetration needle- and the Stud driving method have been successfully proved on tunnel jobsites all over the world.

For determination of strength beyond 10 N/mm² cores are generally taken from the sprayed concrete.

2.4 Summary of test methods

Strength range	Method	Cartridge	Power setting DX 450-SCT	Max aggre-gate	Mix	Specifica-tion**
0.2 to 1.0 MPa	Penetration needle method	-	-	0-8 0-11 0-16	mixed dolomitic limestone (not relevant for this method)	EN 14488-2 ÖVBB 1999 ÖVBB 2006 ÖVBB 2009
1 to 8 MPa	Stud driving method Hilti DX 450	White***, Special-method	1*	0-8/11	mixed dolomitic limestone	ÖVBB 1999
2 to 16 MPa	Stud driving method Hilti DX 450-SCT	Green Standard-method	1*	0-8/11 0-16	mixed dolomitic limestone	EN 14488-2 ÖVBB 1999 ÖVBB 2006 ÖVBB 2009
				0-16	hard aggregate (diabase)	EN 14488-2
17 to 56 MPa	Stud driving method Hilti DX 450-SCT	Yellow Special-method	2*	0-8/11	mixed dolomitic limestone	ÖVBB 2006

* *calibrated for piston guide L140 (corresponds with used equipment of the Hilti DX 450-SCT, item number 233871), in the exceptional case of the use of the piston guide L125, different power settings need to be applied (see chapter 3.2).*

** *ÖVBB = ÖVBB guideline „Sprayed Concrete“ with the corresponding edition year (all available in English except ÖVBB 2009)*

*** *former method, generally not used anymore*

Remark: Detailed operating instructions and evaluation rules for the penetration needle method are given in the quoted specifications.

3 Stud driving method Hilti DX 450-SCT

3.1 Steps of operation

The general procedure is the same for the standard-method and the special-method considering the respective safety provisions.

1. Driving of a Hilti threaded stud X-M6-8-52-D12, X-M6-8-72-D12 or X-M6-8-95-D12 by means of the Hilti powder-actuated tool DX 450-SCT.
   → Standard-method „Green cartridge“, power setting 1.
   → Special-method „Yellow cartridge“, power setting 2.
2. Measure and record standoffs NVS above concrete surface.
3. Calculate depth of penetration h_{nom} of threaded stud into concrete.
4. Measure and record pullout load N_u of the threaded studs utilizing the pullout test device Hilti Mark 5 or Hilti HAT 28 (Hilti Anchor Tester 28)
5. Calculate the ratio of pullout load to penetration depth (N_u/h_{nom}) of each threaded stud.
6. Calculate the mean ratio (N_u/h_{nom})
7. Calculate the sprayed concrete strength utilizing calibration curves.
   → Standard-method „Green cartridge“, calibration curve, appendix 3
   → Special-method „Yellow cartridge“, calibration curve, appendix 4

Remarks:

In case the old testing device Hilti Tester 4 is used, it is required to correct the gauge readings with a tester-specific calibration sheet: N_u → N_u' (see appendix 1 and 2). If the tester Mark 5 is used, a correction of the gauge readings is not necessary. It applies then $N_u = N_u'$.

In the guideline „Sprayed Concrete“ of the ÖVBB, the pullout loads N_u are designated as F and the penetration depth h_{nom} is designated with L.

The tester HAT28 is identical with the Tester Mark 5. HAT28 corresponds with the new tester designation.

3.2 Test equipment

Powder-actuated tool:	**DX 450-SCT**  **Equipment**: • **L 140** piston guide[1] • **45/SL 1** base plate • **45/FL 1** fastener guide • **45/M6-8L** piston[2]
M6 threaded studs:	**X-M6-8-52 D12**, total length 60 mm **X-M6-8-72 D12**, total length 80 mm **X-M6-8-95 D12**, total length 103 mm 
Cartridges:	**6.8/11M green** for f_c = 2 to 16 N/mm^2, the Standard-method **6.8/11M yellow** for f_c = 17 to 56 N/mm^2
Tensile tester:	**Hilti Mark 5** or **HAT28** with threaded button **6/M6**

Order information

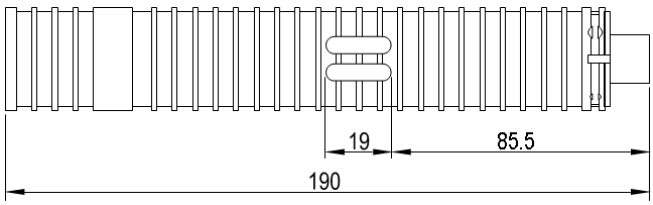
The powder-actuated tool DX 450-SCT – delivered in a testing tool-box – can be ordered with the item number 233871. The tensile tester needs to be ordered separately. However, the Hilti tool-box offers space for the tensile tester Mark 5, threaded studs and cartridges. A summary of all relevant item numbers is given in appendix 7.

Remark with respect to different piston guide L125

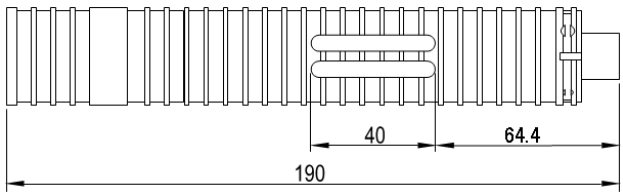
The powder-actuated tool DX 450-SCT is assembled with the piston guide L140. This complies with the common practice in many markets (e.g. Austria). In some markets, the tool DX 450 L was formerly also used with the different piston guide L125. When using the piston guide L125, the driving energy reduces.

The geometry of these piston guides differs in the length of the slots releasing the combustion gas (40 mm in case of the L125 und 19 mm in case of the L140). Therefore, the piston guide can be easily identified with the length of these slots.

Standard-equipment DX 450-SCT, **L 140** piston guide (high energy), short slots (19 mm)



L 125 piston guide (low energy): long slots (40 mm)



In the exceptional case that only a L125 piston guide is available (e.g. when using an older tool DX 450-L), the stud driving method can be applied as well. However, different power settings have to be used as follows.

Standard-method: Green cartridge, power setting 1.625
Special-method: Yellow cartridge, power setting 2.5

[1] Note: In the ÖVBB Guideline, the former designation 45/KFL is still used.
[2] Note: In the ÖVBB Guideline, the former designation 45/NKL is still used.

Hilti Mark 5 respectively HAT28 tensile tester

Hilti recommends to use the Mark 5 respectively HAT28 tensile tester for use in this method of testing. The tester HAT28 is identical with the Tester Mark 5. HAT28 corresponds with the new tester designation.

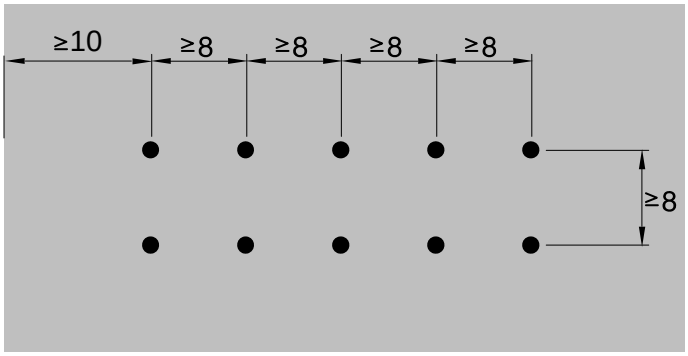
- The Mark 5 respectively HAT28 tensile tester can be used with different gauges, which are attached with a quick-coupler allowing quick exchange of gauges. For the standard-method with Green cartridge, the use of the 0 – 5 kN gauge is recommended, which allows accurate and easy reading. When using the Special-method with Yellow cartridge, exceeding the 5 kN limit is possible. In this case other gauges with higher loads 0 – 10 kN, 0 – 15 kN, 0 – 20 kN or 0 – 25 kN are available (see order information appendix 7).
- Another advantage of the Mark 5 respectively HAT28 tensile tester – compared with its predecessor Hilti tester 4 – is the bigger stroke of 50 mm.

To use the Mark 5 respectively HAT28:

1. Put the M6 threaded button on the threaded stud.
2. Make sure that the red follower needle is set back to zero on the gauge.
3. Bring the jaws of the tester under the threaded button in order to pull the stud centrically.
4. Turn the operating handle clockwise to take up slack first and further applying load by turning the handle till pullout of the stud with corresponding drop of the gauge.
5. Read off the load on the red follower of the gauge.

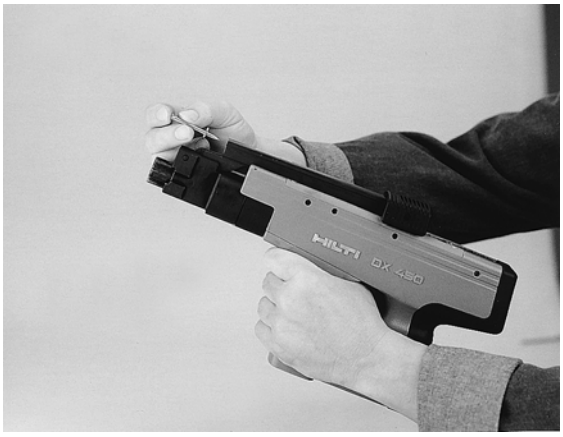
3.3 Driving the threaded studs

- Place 10 studs of the same size for a test series.
- The minimum center-to-center spacing must be at least 8 cm. The edge distance must be at least 10 cm.

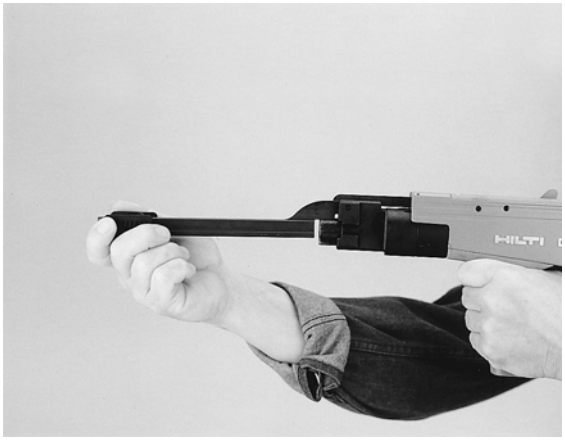


Read the DX 450 operating manual for complete information on safety procedures, tool operation and maintenance. The instructions here are excerpted from the operating manual and cover operation only.

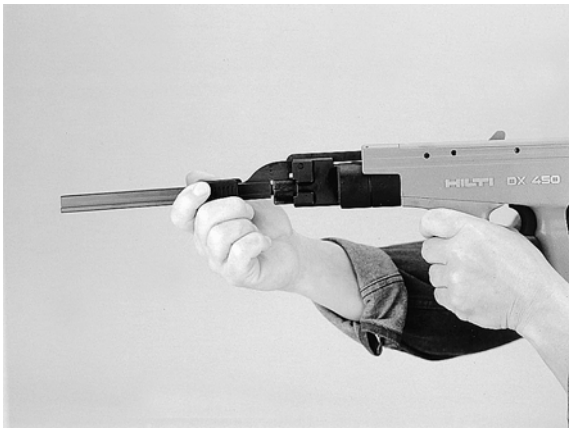
1. Holding the DX 450 with the muzzle upwards, insert the M6 stud point first in the cocking lever and drop the stud.



2. Pull firmly on the loading grip to release the cocking lever and swing it forwards 180° till it is aligned with the barrel of the tool.



3. Push the loading grip as far back as it will go. (this positions the M6 stud properly in the tool).
4. Return the grip forward and swing the cocking lever back to its original position.



5. Insert the cartridge strip into the base of the grip and push it in as far as it will go (this aligns the first cartridge in the proper position).

6. Check power regulation. The power setting must correspond to the calibration used. When the calibration is based on the curves in this manual (appendix 3, appendix 4), the power settings for the powder-actuated fastening tool DX 450-SCT amount as follows:

Standard-method: **Green 1**
Special-method: Yellow 2

1

2

Remark with respect to different piston guide L125

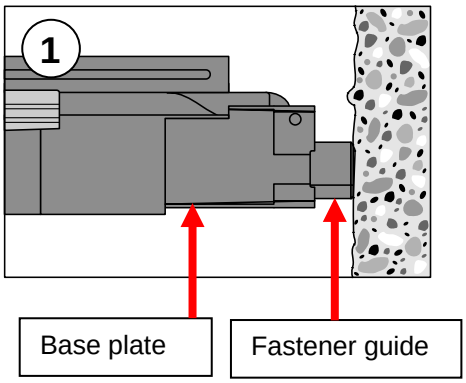
In case of exceptional use of the piston guide L125 (see chapter 3.2) the power settings amount to 1.625 in case of the standard-method „Green cartridge“ 1.625 (hint: the wheel to set the power level clicks into place at the eighth positions) and 2.5 in case of the special-method “Yellow cartridge”.

1.625

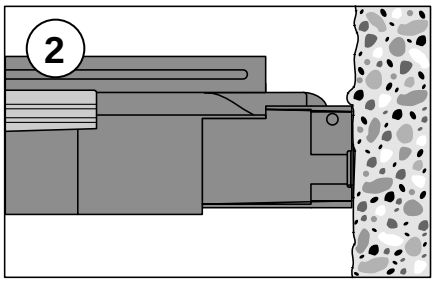
2.5

7. Driving the threaded studs **X-M6-8-52 D12, X-M6-8-72 D12** or **X-M6-8-95 D12**

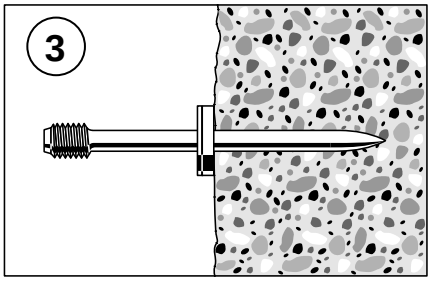
① Bring the tool into position where the stud is to be driven.



② Press the tool against the sprayed concrete surface so that the fastener guide is pushed back into the base plate as far as it can go[1)].



③ Pull the trigger to fire and place the threaded stud.

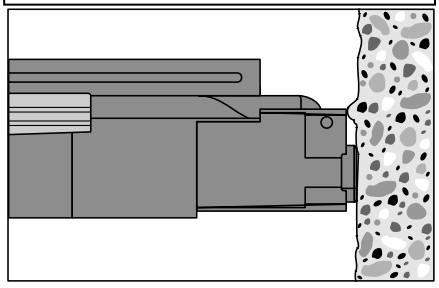


1) For firing to take place, the fastener guide has to be pushed back all the way into the base plate of the tool.

If the fastener guide extends 1 to 2 mm out from the base plate, the trigger can be pulled without firing the cartridge. There is just a “click” to hear and the tool has to be cycled before the trigger can be operated again. Cycling the tool causes the cartridge strip to advance so a loaded cartridge is “lost”. This 1 – 2 mm no-fire window gives the tool a tilt lockout and is a safety feature for applications to normal steel and concrete.

The surface of sprayed concrete is typically very rough and the base plate can hang up on a high spot. This can lead to the “click / no-fire” phenomena described above. To avoid this, make sure that the fastener guide is on a high spot so that base plate does not hang up.

Click / no-fire phenomena

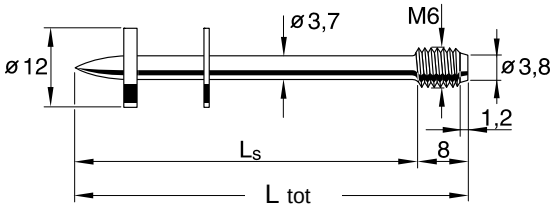


8. Repeat steps 1., 2., 3., 4. and 7. to drive the rest of the threaded studs.

9. Dry immediately after testing – especially after small number of tests – piston and piston guide, in order to avoid corrosion of the parts.

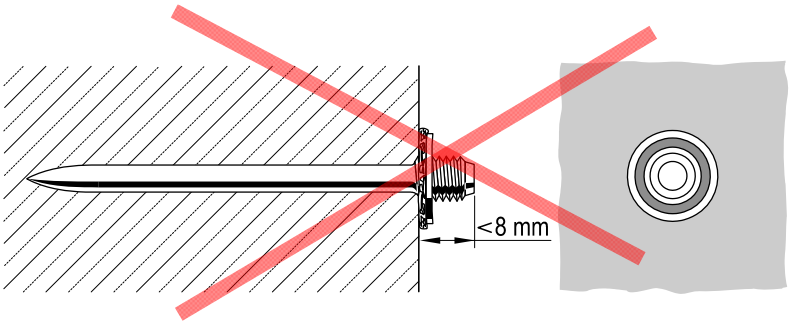
3.4 Threaded stud selection

The threaded stud program for the testing consists of three studs with different shank lengths.



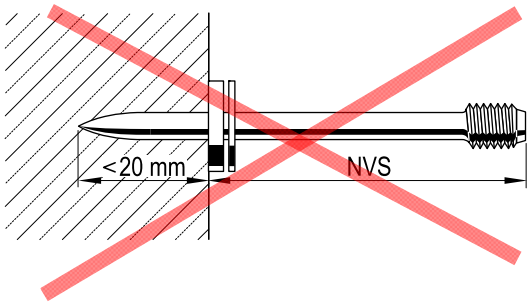
L_s = 52, 72, 95 mm

If the longest stud is driven deeper than its shank length (**NVS** < 8 mm), postpone the test until the sprayed concrete has gained more strength.



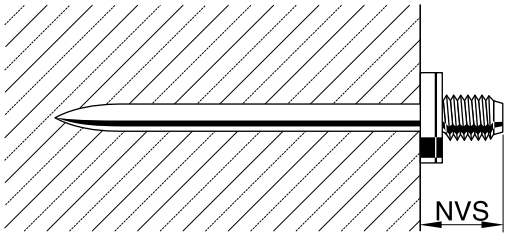
If the depth of penetration into the concrete, **h_{nom}** is less than 20 mm, use the next shorter stud. The depth of penetration calculates from the total stud length L_{tot} minus the standoff (**$h_{nom} = L_{tot} - NVS$**).

Threaded stud	Maximum **NVS** (mm)
X-M6-8-52 D12	60 – 20 = 40
X-M6-8-72 D12	80 – 20 = 60
X-M6-8-95 D12	103 – 20 = 83

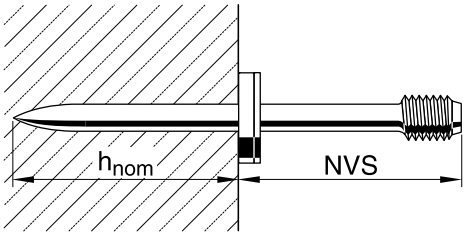


The pullout test is more convenient if the standoff is less than about 30 mm.

Requirement: **NVS** ≥ 8 mm



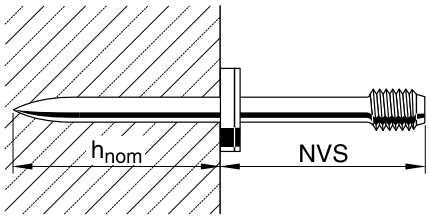
Recommended: **NVS** ≤ 30 mm



3.5 Example: Compressive strength with DX 450-SCT and Green cartridge (Standard-method)

Following the procedures, drive 10 studs of the same size using the green cartridge, power setting 1. A form for the test record is given in appendix 1. The calibration curve is given in appendix 3.

1. For each stud measure the standoff **NVS** and enter it in column (4) of the record form of appendix 1.
2. For each stud calculate the depth of penetration $\mathbf{h_{nom}}$ and enter these in column (5).



Calculation of concrete compressive strength — **Appendix 1**

DX 450-SCT: Standard-method, Green cartridge, power setting 1 *)

Date: 21.08.2000	Powder-actuated test tool: DX 450-SCT Type and serial number: 123123	Air temperature: 20° C	Mix temperature: 32° C	Test by: H. Beck
Gallery/tunnel: Lötschberg	Station: km 7.24		Location: left	Tensile tester: Mark 5
Aggregate size: 0 - 8 mm	Cement: CEM I 42.5R	Accelerator: Type 1a	Time of completing spraying, t_o = 11:30	

(1) Time [h : min.]	(2) Time after spraying completed (1) - t_o [h : min.]	(3) Stud type und Total length L_{tot} [mm]	(4) Standoff NVS [mm]	(5) Penetration h_{nom} = L_{tot} - NVS [mm]	(6) Pullout load N_u Reading, [N]	(7) Actual pullout load $N_{u'}$ **) [N]	(8) $N_{u'}/h_{nom}$ [N/mm]	(9) Mean value $N_{u'}/h_{nom}$ (Σ $N_{u'}/h_{nom}$)/10 [N/mm]	(10) Concrete cube strength Calibr. curve Appendix 3
t =		All measurements and calculations in the same order as studs driven							
16:00	4:30	X-M6-8-52 60 mm	25	35	900	-	25.7		
			18	42	1100	-	26.2		
			23	37	900	-	24.3		
			18	42	1000	-	23.8		
			20	40	1200	-	30.0		
			20	40	1100	-	27.5		
			17	43	1250	-	29.1		
			14	46	1300	-	28.3		
			17	43	1150	-	26.7		
			21	39	1050	-	26.9		
						Σ =	268.5	26.9	

*) Green 1 for standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 1.625.

) this column is reserved for corrected pullout loads, only necessary in case the former Hilti **Tester 4 is used. If the tester **Mark 5** is used: Value in (7) = Value in (6).

3. Use a Hilti Mark 5 tensile tester to pull-out the threaded studs and enter the load readings, $\mathbf{N_u}$, in column (6) of the form.

   Remark: When using the Mark 5 tensile tester, no correction of the readings is required → $\mathbf{N_u} = \mathbf{N_{u'}}$

4. Calculate $\mathbf{N_{u'}/h_{nom}}$ for each reading and enter in column (8). Then, calculate the mean $\mathbf{N_{u'}/h_{nom}}$ and enter it in column (9).
5. With the mean value $\mathbf{N_{u'}/h_{nom}}$ (corresponds with **F/L** in the calibration curve in appendix 3), the concrete compressive strength can be read from the calibration curve in appendix 3. Alternatively, calculate the strength with the formula $\mathbf{f_c} = (\mathbf{N_{u'}/h_{nom}} + 2.7) / 7.69$ (with f_c in N/mm² and $N_{u'}/h_{nom}$ in N/mm).

Calculation of concrete compressive strength

Appendix 1

DX 450-SCT: Standard-method, Green cartridge, power setting 1 *)

Date: 21.08.2000	Powder-actuated test tool: DX 450-SCT Type and serial number: 123123	Air temperature: 20° C	Mix temperature: 32° C	Test by: H. Beck
Gallery/tunnel: Lötschberg	Station: km 7.24		Location: left	Tensile tester: Mark 5
Aggregate size: 0 - 8 mm	Cement: CEM I 42.5R	Accelerator: Type 1a	Time of completing spraying, t_o = 11:30	

(1) Time [h : min.]	(2) Time after spraying completed (1) - t_o [h : min.]	(3) Stud type und Total length L_{tot} [mm]	(4) Standoff NVS [mm]	(5) Penetration h_{nom} = L_{tot} - NVS [mm]	(6) Pullout load N_u Reading, [N]	(7) Actual pullout load $N_{u'}$ **) [N]	(8) $N_{u'}/h_{nom}$ [N/mm]	(9) Mean value $N_{u'}/h_{nom}$ ($\Sigma N_{u'}/h_{nom}$)/10 [N/mm]	(10) Concrete cube strength Calibr. curve Appendix 3
t =		All measurements and calculations in the same order as studs driven							
16:00	4:30	X-M6-8-52 60 mm	25	35	900	-	25.7		
			18	42	1100	-	26.2		
			23	37	900	-	24.3		
			18	42	1000	-	23.8		
			20	40	1200	-	30.0		
			20	40	1100	-	27.5		
			17	43	1250	-	29.1		
			14	46	1300	-	28.3		
			17	43	1150	-	26.7		
			21	39	1050	-	26.9		
						Σ =	268.5	26.9	3.8

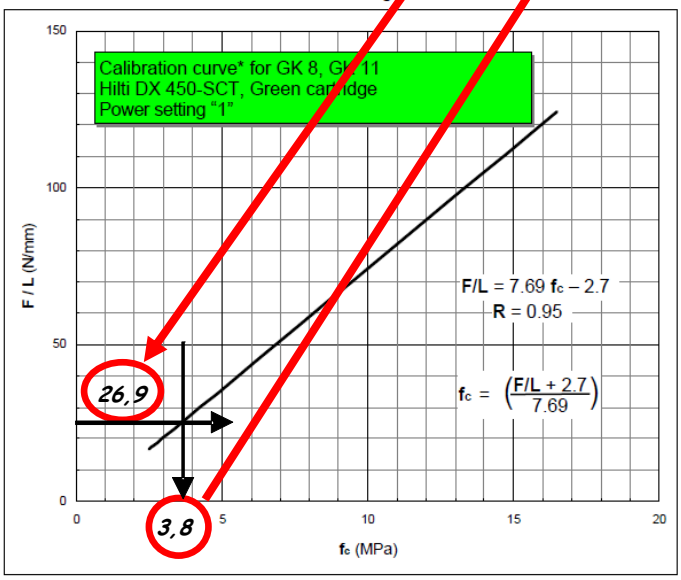
*) Green 1 for standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 1.625.

) this column is reserved for corrected pullout loads, only necessary in case the former Hilti **Tester 4 is used. If the tester **Mark 5** is used: Value in (7) = Value in (8)

6. Enter the value of the strength $\mathbf{f_c}$ in the form appendix 1.

Appendix 3

Calibration curve - Standard-method
DX 450-SCT, Green cartridge, Power setting 1



* The source of this calibration curve is the ÖVBB-guideline "Sprayed Concrete" (editions 1999, 2006, 2009) and EN 14488-2, respectively. Its accuracy depends on the characteristics of the sprayed concrete actually used and its applicability is therefore limited. Hilti recommends that project-specific calibration curves be generated.

* Power setting „Green 1" applies for the standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 1.625.

7. For older and higher strength sprayed concrete, the yellow cartridge and the threaded studs **X-M6-8-52 D12** should be used (Special-method). In that case, use the form of appendix 2 and the calibration curve of appendix 4.

3.6 Work instructions according to the ÖVBB-guideline „Spritzbeton" (Sprayed Concrete), Edition 12/2009: Stud driving method (measuring range 2 to 16 N/mm²)

The stud driving method is covered by several specifications (see chapter 2.4). The following text provides a translation of the work instructions given in the ÖVBB-guideline "Spritzbeton" (Sprayed Concrete), Edition 12/2009:

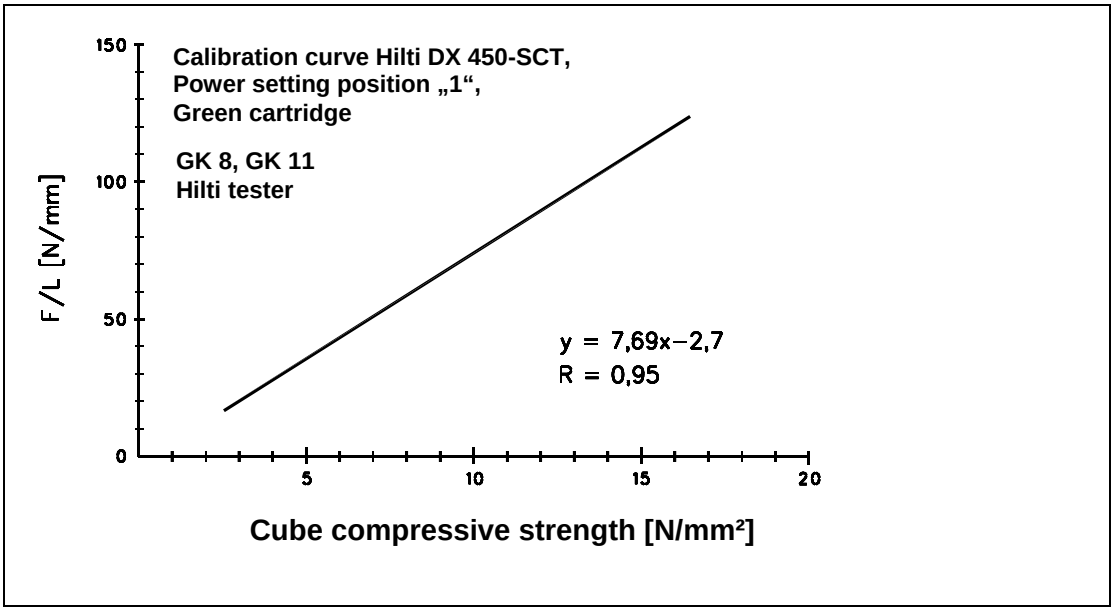
"Threaded studs are driven into the concrete and the depth of penetration is determined. Then the studs are pulled out and the pull-out force is measured. The ratio of pull-out force to penetration depth is the parameter used to determine the compressive strength. The powder-actuated tool needs to drive the studs with constant energy at least 20 mm into the young concrete. The Hilti piston tool DX 450-SCT with Green cartridge is used for example: driving energy E = 96 ± 8 Joule (piston guide L 140 and stud diameter = 3.7 mm).

The pull-out force is determined by means of a pull-out device (e.g. Hilti Tester 4 (observe required calibration curve of this tester) or Hilti Mark 5 with an accuracy of < 5 % according to EN 14488-2). For the tool DX 450-SCT calibration curves are provided. The procedure has been calibrated for sprayed concretes commonly used in tunnel construction (see Figures). In case of deviations – particularly as regards Mohs' hardness of aggregates – a separate calibration has to be performed.

Instructions for testing and evaluation (explanations given in annex of guideline and according to paragraph 5.2 of EN 14488-2)

- *Understand safety requirements of powder-actuated tool.*
- *Load stud and set to power setting position „1"*
- *Position the tool and drive the studs into the concrete, 10 individual tests for each test sequence with a spacing > 80 mm and an edge distance > 100 mm.*
- *Measure and record standoff of studs.*
- *Determine depth of penetration (minimum = 20 mm).*
- *Fasten nut and pull out studs in the same order as driven. Apply load centrically with the stud!*
- *Record pull-out force, time and place of testing, correct force by means of calibration curve, if required.*
- *Determine the ratio of pull-out force „F" to penetration depth „L"*
- *Establish individual F/L values*
- *Read cube compressive strength from calibration curve on the basis of the mean F/L-value. Extrapolations are not permissible.*

The procedure can be used for measurements at any location without advance preparation. Hence, the method is well suited for quality control measurements. With measuring points distributed over larger surfaces, fluctuations in concrete strength can be detected."



3.7 Evaluation in the normal case

The evaluation is done in the normal case using the calibration curves given in appendix 3 and 4.

Property	Test method	Conformity- and Identity criteria
Early strength class	As described	Compliance with the required J-class over time

The frequency of testing is defined in the specifications:

Testing	Precon-struction testing	Conf.-testing	Inspection category ÜK I	Inspection category ÜK II	Inspection category ÜK III	Identity testing
Early strength class	x	x	every 2 month or every 5´000 m²	monthly or every 2´500 m²	2 per month or every 1´250 m²	every 20´000 m²

3.8 Calibration

The referenced calibration curves (appendix 3 and 4) are well suited for mixes and aggregates commonly used in Central Europe. For their determination, different mix designs varying aggregate, grading line, binder content and water-cement-ratio were considered. There is a separate calibration curve for diabase given in EN 14488-2. Compressive testing for calibration was done with 20-cm-cubes.

In case of deviating mixes (compared with appendix 5), especially with respect to the Mohs‘ hardness of the aggregates, it is recommended to develop a new calibration curve. The corresponding procedure is also shortly described in the ÖVBB-Guideline:

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.

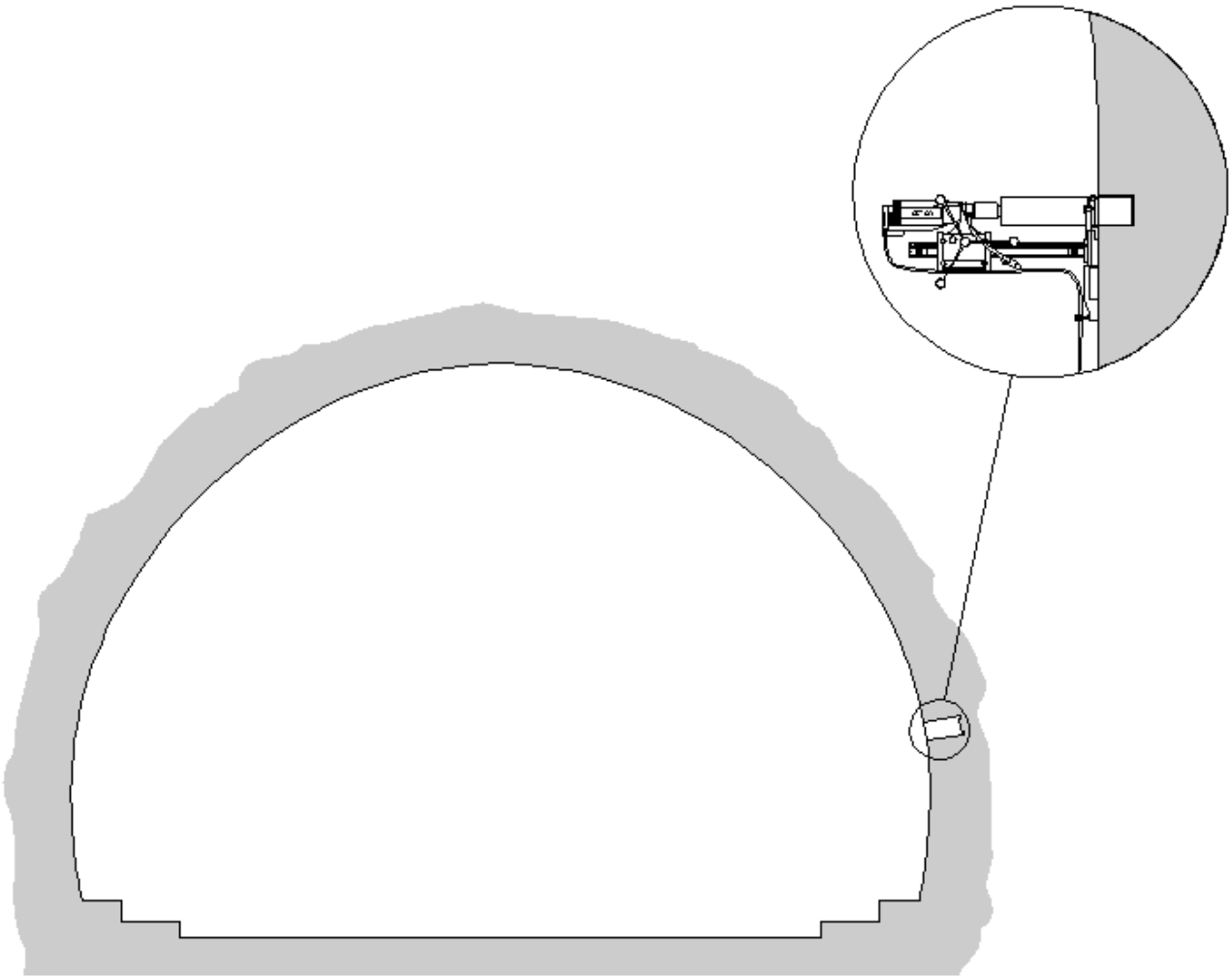
In parallel stud driving tests according to the respective test procedure will be executed. These are done on separately produced plates of about the same cubature, but with a thickness of 10 cm. (The temperature development in the cubes and the plates should be similar, in order to test with the same 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.

4. Concrete cores

This method is applicable for concrete strength $\mathbf{f_c} \geq 10$ N/mm^2. The rules given in EN 12504-1 are to be observed.

For taking the concrete cores of a nominal diameter of 100 mm, the following Hilti diamond core system is for example recommended:

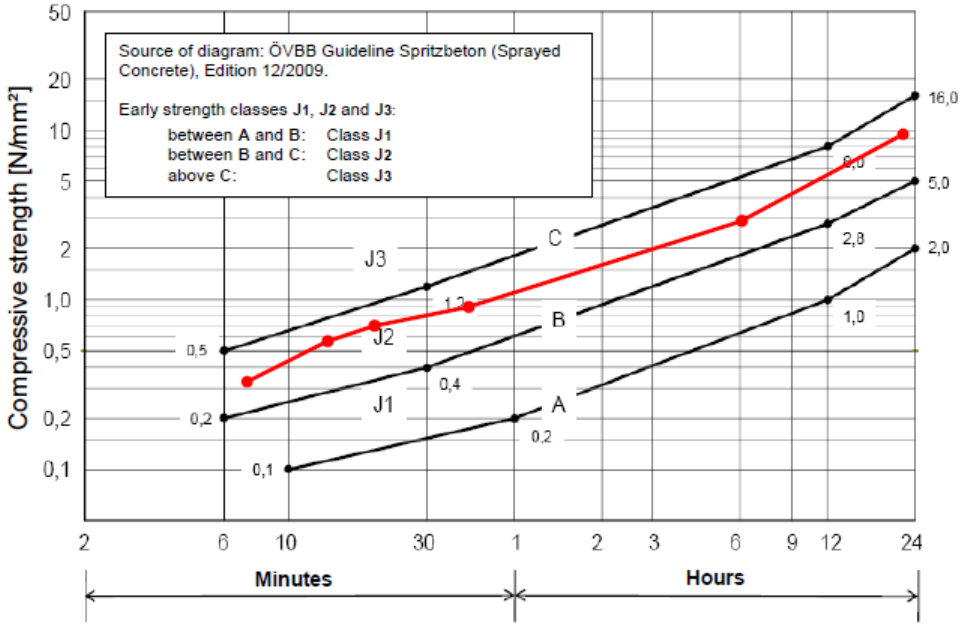
- DD 150-U 230V diamond coring tool (Item number: 433323)
- DD-ST 150-U drill stand (Item number: 435666)
- Diamond core bit DD BI 102/320+ PS (Item number: 2022443), working length: 320 mm
  Diamond core bit DD BI 102/320+ PL (Item number: 2022333), working length: 320 mm



5. Strength development of young sprayed concrete

Entering the measured compressive strength values into the diagram given in appendix 6 shows the development of the strength of the young sprayed concrete.

Development of strength of young sprayed concrete				**Appendix 6**
Date: 21.08.2000	Powder-actuated test tool: DX 450-SCT Serial number: 123123	Air temperature: 20° C	Mix temperature: 32° C	Test by: H. Beck
Gallery/tunnel: Lötschberg		Station: km 7.24	Location: left	Tensile tester: Mark 5
Aggregate size: 0 - 8 mm	Cement: CEM I 42.5R	Accelerator: Typ 1a	Time spraying completed, t_o = 11:30	



In the given example, all values are between the line B and C. This means, that the sprayed concrete meets the requirements of the early strength class J_2.

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

Calculation of concrete compressive strength

DX 450-SCT: Standard-method, Green cartridge, power setting 1 *)

Appendix 1

Date:	Powder-actuated test tool: Type and serial number:	Air temperature:	Mix temperature:	Test by:
Gallery/tunnel:	Station:		Location:	Tensile tester:
Aggregate size:	Cement:	Accelerator:	Time of completing spraying, t_o =	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Time [h : min.]	Time after spraying completed (1) - t_0 [h : min.]	Stud type und Total length L_{tot} [mm]	Standoff **NVS** [mm]	Penetration h_{nom} = L_{tot} - **NVS** [mm]	Pullout load N_u Reading, [N]	Actual pullout load $N_{u'}$ **) [N]	$N_{u'}/h_{nom}$ [N/mm]	Mean value $N_{u'}/h_{nom}$ (Σ $N_{u'}/h_{nom}$)/10 [N/mm]	Concrete cube strength Calibr. curve **Appendix 3**
t =			**All measurements and calculations in the same order as studs driven**						
						Σ =			

*) Green 1 for standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 1.625.

) this column is reserved for corrected pullout loads, only necessary in case the former Hilti **Tester 4 is used. If the tester **Mark 5** respectively **HAT28** is used: Value in (7) = Value in (6).

Calculation of concrete compressive strength

DX 450-SCT: Special-method, Yellow cartridge, power setting 2 *)

Appendix 2

Date:	Powder-actuated test tool: Type and serial number:	Air temperature:	Mix temperature:	Test by:
Gallery/tunnel:	Station:		Location:	Tensile tester:
Aggregate size:	Cement:	Accelerator:	Time of completing spraying, t_o =	

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Time [h : min.]	Time after spraying completed (1) - t_0 [h : min.]	Stud type und Total length L_{tot} [mm]	Standoff **NVS** [mm]	Penetration h_{nom} = L_{tot} - **NVS** [mm]	Pullout load N_u Reading, [N]	Actual pullout load $N_{u'}$ **) [N]	$N_{u'}/h_{nom}$ [N/mm]	Mean value $N_{u'}/h_{nom}$ (Σ $N_{u'}/h_{nom}$)/10 [N/mm]	Concrete cube strength Calibr. curve **Appendix 4**
t =			**All measurements and calculations in the same order as studs driven**						
						Σ =			

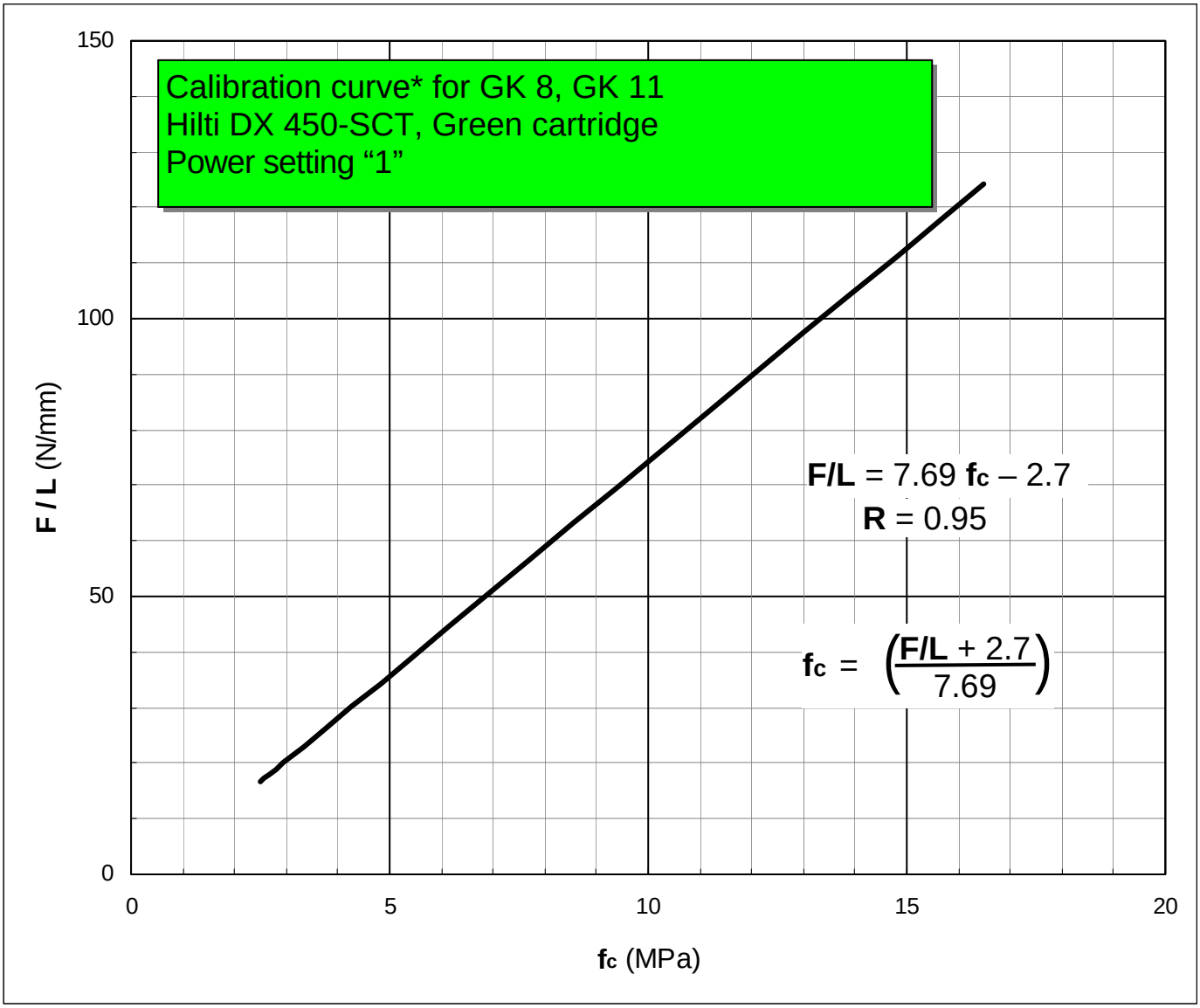
*) Yellow 2 for standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 2.5.

) this column is reserved for corrected pullout loads, only necessary in case the former Hilti **Tester 4 is used. If the tester **Mark 5** respectively **HAT28** is used: Value in (7) = Value in (6).

Calibration curve - Standard-method

DX 450-SCT, Green cartridge, Power setting 1

Appendix 3



* The source of this calibration curve is the ÖVBB-guideline “Sprayed Concrete” (editions 1999, 2006, 2009) and EN 14488-2, respectively. Its accuracy depends on the characteristics of the sprayed concrete actually used and its applicability is therefore limited. Hilti recommends that project-specific calibration curves be generated.

* Power setting „Green 1” applies for the standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 1.625.

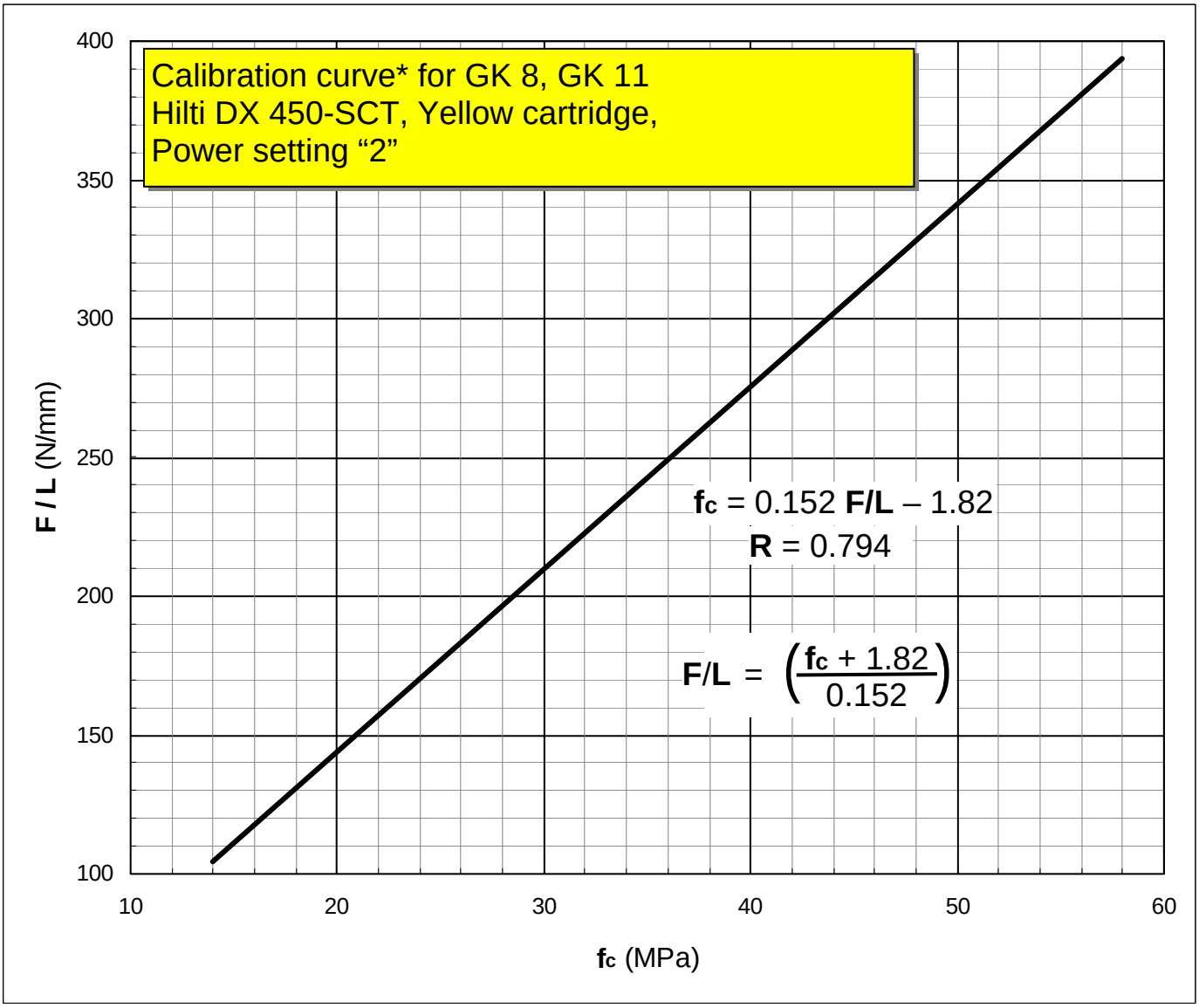
* F/L = $\mathbf{N_u}$/$\mathbf{h_{nom}}$

* R = Coefficient of correlation

Calibration curve - Special-method

DX 450-SCT, Yellow cartridge, Power setting 2

Appendix 4



* The source of this calibration curve is the ÖVBB-guideline “Sprayed Concrete” (editions 1999, 2006). Its accuracy depends on the characteristics of the sprayed concrete actually used and its applicability is therefore limited. Hilti recommends that project-specific calibration curves be generated.

* Power setting „Yellow 2” applies for the standard equipment of the tool DX 450-SCT. In case a tool DX 450 with a piston guide L125 is used, the power setting amounts to 2.5.

* F/L = $\mathbf{N_u}$/$\mathbf{h_{nom}}$

* R = Coefficient of correlation

Mixes used for calibration (Standard-method)

Appendix 5

Mix design used for the calibration of the Hilti DX 450-SCT (with piston guide L140)								
cement	**W/Z**	**Z/K**	**GK**	Grade line	Aggregate	Cons.	**LP**	**RG**.
420 kg PZ 375	0.4	1 : 4.31	8	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	mixed dolomitic limestone	K1	3.3	2.430
420 kg PZ 375	0.45	1 : 4.183	8	$\mathbf{B_8}$ round grain	___ ,, ___	K1	5.4	2.296
440 kg PZ 475 (H)	0.47	1 : 3.86	8	$\mathbf{B_8}$ round grain	___ ,, ___	K1	2.36	2.36
420 kg PZ 375	0.45	1 : 4.183	16	$\mathbf{B_{16}}$ round grain	___ ,, ___	K2	2.4	2.39
420 kg PZ 475 (H)	0.42	1 : 4.39	16	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	___ ,, ___	K1	2.6	2.456
420 kg PZ 375	0.4	1 : 4.31	16	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	___ ,, ___ + diabase 8/16	K1	2.7	2.48
Mix design used for the calibration of the penetration method and preliminary tests for the Hilti DX 450-SCT (with piston guide L140)								
cement	**W/Z**	**Z/K**	**GK**	Grade line	Aggregate	Cons.	**LP**	**RG**.
355 kg PZ 375 HS + additives	0,4		8	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	mixed dolomitic limestone			
400 kg PZ 375	0,43	1 : 4.76	8	$\mathbf{B_8}$ round grain	___ ,, ___	K1	3.9	2.378
397 kg PZ 375	0,42	1 : 4.49	16	$\mathbf{B_8}$ angular grain	___ ,, ___	K1		
230 kg PZ 375	0,65	1 : 9.19	16	$\mathbf{B_{16}}$ round grain	___ ,, ___	K1	2.1	2.320
400 kg PZ 375	0,5	1 : 4.58	16	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	___ ,, ___	K3	2	2.396
400 kg PZ 375	0,43	1 : 4.76	16	$\frac{\mathbf{A}+\mathbf{B}}{2}$ angular grain	___ ,, ___	K1	---	2.450

ABBREVIATIONS:

W/Z water/cement ratio
Z/K cement/aggregate ratio
GK maximum grain size
Cons. consistency of fresh concrete
LP air content
RG bulk density of fresh concrete
PZ Portland cement
(H) blast furnace slag

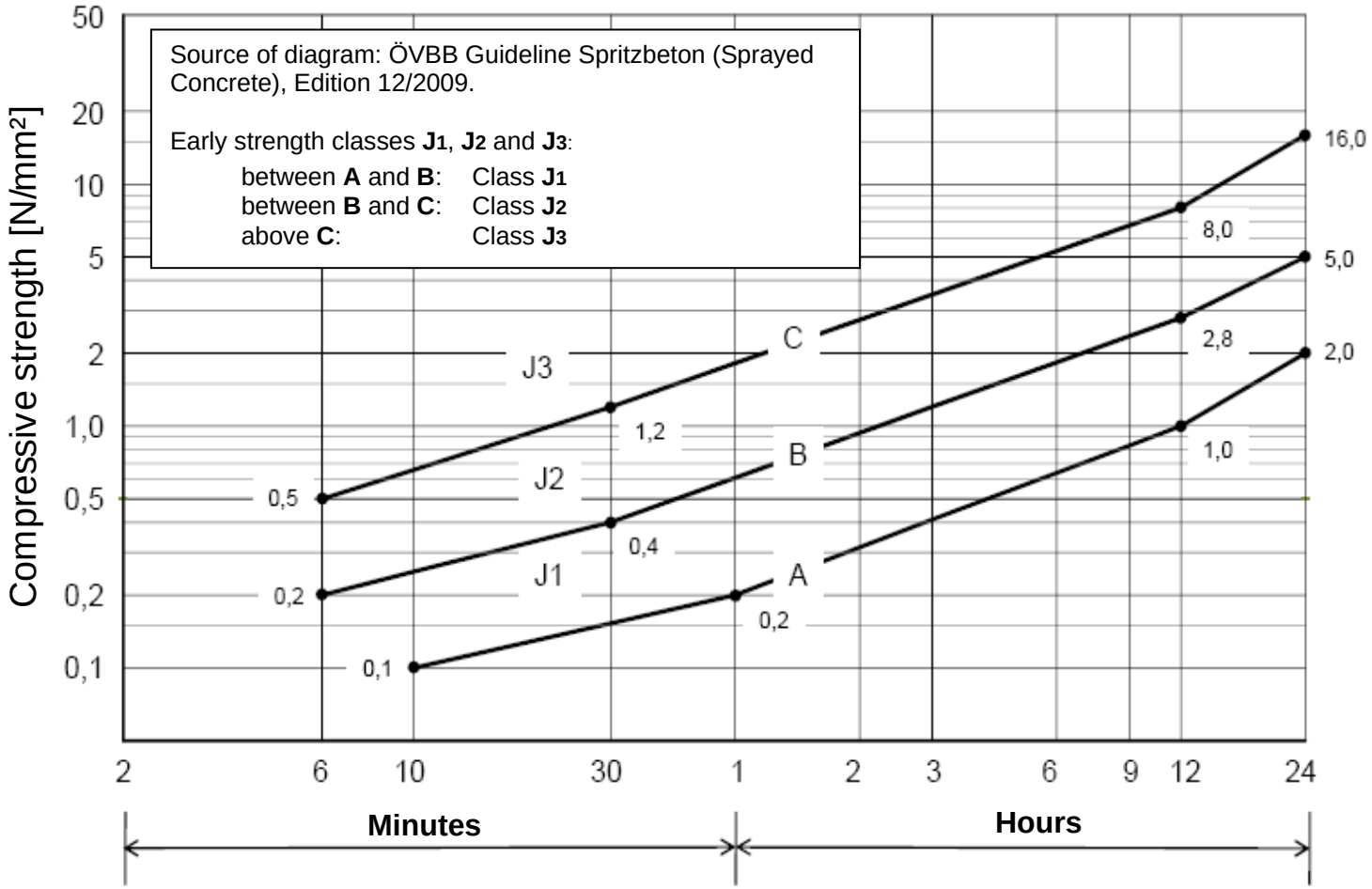
Cement designations according to the previously valid Austrian standards.

The calibration curve of **Appendix 3** was established with these concretes. In case that the concrete mix to be checked varies significantly from the mixes shown here (especially with respect to the Mohs' hardness), then a special calibration curve for the current mix has to be made.

Development of strength of young sprayed concrete

Appendix 6

Date:	Powder-actuated test tool: Serial number:	Air temperature:	Mix temperature:	Test by:
Gallery/tunnel		Station:	Location:	Tensile tester:
Aggregate size:	Cement:	Accelerator:	Time spraying completed, t_o =	



Appendix 7

Order information of powder-actuated tool DX 450-SCT and the required test equipment.

Taken from leaflet:

Hilti DX 450-SCT, Sprayed Concrete Testing System – Gain more from acceleration (2008)

DX 450-SCT

Ordering designation		Item no.
DX 450-SCT	①	233871

Comprising a Hilti DX 450-SCT powder-actuated tool (long version) including 45/SL 1 base plate, 45/FL1 fastener guide, L140 piston guide and 45/M6-SL piston. This kit also includes the cleaning set, safety equipment and operating instructions. Packed in an impact-resistant plastic Hilti toolbox.

Please note: This item number does not include the tester, tester accessories, threaded studs or cartridges.

Accessories, consumables and spare parts for DX 450-SCT

45/SL1 base plate assembly	②	000732
45/FL1 fastener guide	③	000730
L140 piston guide	④	000787
45/M6-8L piston	⑤	088058
X-M6-8-52D12 threaded stud (100 pcs/box)	⑥	306050
X-M6-8-72D12 threaded stud (100 pcs/box)		306051
X-M6-8-95D12 threaded stud (100 pcs/box)		306052
6.8/11 green cartridge	⑦	050351
6.8/11 yellow cartridge		050352

Tester Mark 5

Tester Mark 5		236442

Comprising Hilti Tester Mark 5, 0-5 kN force gauge, M6 adapter set and operating instructions, packed in an impact-resistant plastic Hilti toolbox

Accessories and spare parts for the Tester Mark 5

Tester Mark 5 body only	⑧	285523
0- 5 kN force gauge	⑨	285525
0-10 kN force gauge		285526
0-15 kN force gauge		285527
0-20 kN force gauge		285528
0-25 kN force gauge		285529
0-30 kN force gauge		274311
6/M6 adapter set	⑩	285562

<u>Remark</u>:

When ordering the test equipment DX 450-SCT with the item number 233871, the tester Mark 5 respectively HAT28 is not included. The tester needs to be ordered separately.