ANCHORING TO STEEL FIBRE-REINFORCED CONCRETE

Introduction to Hilti solutions approved for the use in SFRC

Version 1.1
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INTRODUCTION AND SCOPE OF THE ARTICLE

Throughout history, building materials have been reinforced with a variety of materials. In ancient times horsehair was used to reinforce mortar and straw was used to reinforce mudbricks. Moving into the 1900s, asbestos fibres found their way into concrete. The 1950s marked the emergence of composite materials, making fibre-reinforced concrete a significant area of exploration. In modern engineering, fibres of various materials like ceramics, plastics, cement, and gypsum products are used as fibres in plain concrete to improve composite features.

Lately, the construction industry is experiencing a growing trend – the use of steel fibre-reinforced concrete (SFRC) instead of traditional plain concrete for structural and non-structural concrete applications. Multiple research studies have shown that SFRC has several benefits compared to traditional concrete such as increased tensile strength, higher resistance to crack opening, improved durability and improved resistances against fatigue, impact, and abrasion. Many of the available publications on this topic discuss the necessity to comprehend the performance of fastening systems in these specialized concretes. However, until recently no European Technical Assessment (ETA) explained the behaviour of anchoring solutions.

Today, Hilti brings you the first anchoring solutions approved for fastening in SFRC. The aim of this paper is threefold: to emphasize the importance of the growing trend to use this specialized concrete, to present an overview of the existing regulatory framework covering anchoring applications in SFRC, and to educate on the Hilti systems that are approved for use in SFRC: HAS-D with HIT-HY 200-A V3/-R V3 and HUS4 in carbon steel.

THE IMPORTANCE OF THE TOPIC

To meet the growing demand for expanding applications, the EOTA Expert Group Fixings (EGF) has recently focused on incorporating steel fibre-reinforced concrete and the complete range of concrete strength classes defined in EN 1992-4:2018 into the European Assessment Documents (EADs) [1]. The latest updates in a fastener qualification, such as EAD 330499-02-0601 and variant EAD 330232-01-0601-v05 [2] [3], introduce testing programs for fastener qualification in both normal weight concrete (C12/15 – C90/105, per EN 1992-4:2018) and steel fibre-reinforced concrete (SFRC; strength classes C20/25 to C50/60).

EAD 330499-02-0601 and EAD 330232-01-0601-v05 have been recently approved by the European Commission. These programs adhere to the logic of normal weight concrete testing but include additional test series in SFRC to demonstrate equivalency, and a provision according to EN 14889 which sets a maximum limit of 80 kg/m^3 on the volume of steel fibres in the concrete.

For design purposes, a statement will be given in the relevant ETAs to allow following EN 1992-4 regulations for fasteners adequately qualified in SFRC. Static/quasi-static and seismic loading and performance in case of fire are already considered in EAD 330232-01-0601-v05, while fatigue cyclic loading actions are currently not addressed in EOTA.

The publication of EAD 330499-02-0601 and variant EAD 330232-01-0601-v05 in the official journal of the European Union is on the horizon. ETAs can already be issued.

The option of a national-level qualification, such as through a general design approval in Germany ("Allgemeine Bauartgenehmigung"), remains available for non-regulated conditions, such as fatigue cyclic loading.

The ongoing revision of Eurocodes in the successor document to EN 1992-1-1 will address the design of steel fibre-reinforced concrete in a new informative annex. It is important to point out here that the new regulations for fasteners in concrete only cover steel fibres and no other fibre types, nor a combination of steel fibres and other fibre types.

STEEL FIBRE-REINFORCED CONCRETE

Plain unreinforced concrete has a low tensile strength and a low strain capacity at fracture. Concrete's fractile behaviour is enhanced by incorporating steel fibres into the mix. This transforms the brittle matrix of conventional concrete into a composite material, strengthened by randomly oriented, short, and discontinuous steel fibres with a specific geometry. The most significant properties of SFRC are the improved load-bearing behaviour, limitation of crack widths, improved shock and abrasion resistance, increased resistance to flaking and advanced notice of failure. Following crack initiation in SFRC, internal forces are efficiently transferred through fibres, optimizing stress redistribution across the component cross-section (see figures 1 and 2). These advantages mean that we see more and more SFRC relevant applications (e.g., industrial floors) which are subject to high loads and impact [4].

In addition, steel fibres may even replace standard bar reinforcement to a certain degree, since reinforcing with steel-fibres is a more productive process for casting large areas, e.g. in industrial floorings.

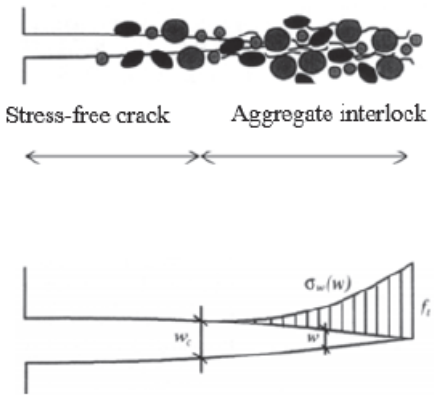

Figure 1: Stress distribution in Normal concrete [5]

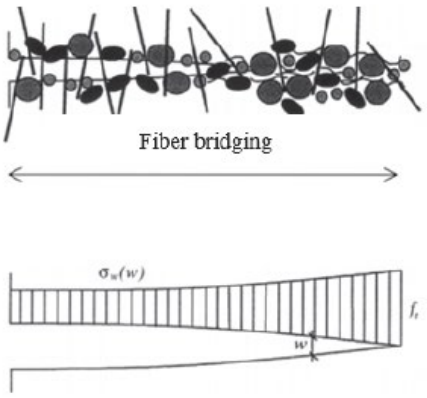

Figure 2: Stress distribution in Steel-fibre reinforced concrete [5]

Steel fibres

Steel fibres are commonly characterized by their shape, cross-section and length, aspect ratio, and tensile strength. The aspect ratio, defined as the fibre length divided by the equivalent diameter of a fibre, influences the maximum volume of fibre per cubic meter of concrete. In concrete containing normal quantities of coarse aggregate, exceeding 1% steel fibre dose rate (approximately 80 kg/m^3) is rare due to the interference and impact on workability between the fibres and coarse aggregate. Typically, steel fibres account for 0,3% to 0,6% of the overall concrete volume (25 to 45 kg/m^3), with higher doses used in specialized concrete with minimal coarse aggregate.

EN 14889-1 ‘Fibres for concrete, Part 1: Steel fibres - Definitions, specifications and conformity’ classifies steel fibres into five groups [6]. Group I fibres are the most widely used steel fibres:

- Group I: Cold-drawn wire
- Group II: Cut sheet
- Group III: Melt extracted
- Group IV: Shaved cold drawn wire
- Group V: Milled from blocks

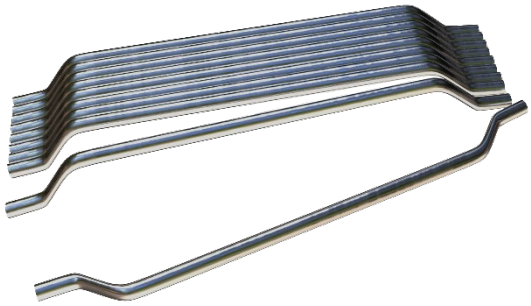

Figure 3: Example of steel fibres

TYPICAL APPLICATIONS

In contemporary construction, conventional fibre-reinforced concrete (FRC), like SFRC, is extensively employed in industrial flooring. Its primary purposes include mitigating premature shrinkage cracks and enhancing resistance to impact loads or abrasion. Post-installed anchors are also applied in such settings, securing industrial components or heavy machinery. In fact, the crack bridging mechanism of fibres and the less brittle concrete breakout failure mode improve the load-bearing capacity of SFRC, making it an ideal base material to install concrete anchors [4].

Figure 4: Industrial flooring

Figure 5: Civil Construction (pre-cast)

Approximately 60% of all new industrial floors are currently made using steel fibre concrete. They are especially prevalent in places where concrete floors must withstand heavy mechanical loads, such as in high rack warehouses, production halls, or logistics centres.

Additionally, steel fibre-reinforced concrete is used in civil construction. The use of steel fibres in a precast element factory can optimise processes considerably, with significant cost savings. Other SRFC applications may include fibres mixed into thin concrete elements, for example, in a residential sector, shotcrete applications and applications within a specialized construction.

Although steel fibres are used in tunnels, in some cases this application also contains a portion of polymer fibres to prevent spalling in case of fire.

SFRC APPROVED HILTI ANCHORING SYSTEMS

	Anchor	Diameter	Static	Fatigue	Seismic
	HAS-D with HIT-HY 200-A V3 and -R V3	M12-M20	ETA-18/0972	abG Z-21.3-2155	-
	HUS4-H/HF/HR/C/CR/A/AF	8mm-16mm	ETA-20/0867	-	ETA-20/0867 (for SFRC only C1 loading is approved)

Figure 6: Approved Hilti anchoring systems for the use in SFRC

HAS-D with HIT-HY 200-A V3 and -R V3

The ETA-18/0972 for HAS-D with injection systems Hilti HIT-HY-200-A, -R, and -R V3 has been updated in November 2023 to include the system performance under static and quasi-static loads in SFRC with steel fibres Group I, up to a maximum content of 80 kg/m^3 [7].

Based on this update, HAS-D can now be designed according to EN 1992-4 also in SFRC. Additionally, a German national approval abG Z-21.3-2155 was issued in March 2024 to assess the performance of HAS-D under fatigue cyclic load, in reference to the data presented in the ETA-18/0978 [8].

Deutsches Institut für Bautechnik DIBt

Approval body for construction products and types of construction

Bautechnisches Prüfamt

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Designated according to Article 29 of Regulation (EU) No 305/2011 and member of EOTA (European Organisation for Technical Assessment)

European Technical Assessment **ETA-18/0972 of 30 November 2023**

English translation prepared by DIBt - Original version in German language

General Part

Technical Assessment Body issuing the European Technical Assessment:	Deutsches Institut für Bautechnik
Trade name of the construction product	Injection system Hilti HIT-HY 200-A, HIT-HY 200-R, HIT-HY 200-A V3 and HIT-HY 200-R V3 with HAS-D
Product family to which the construction product belongs	Bonded fasteners and bonded expansion fasteners for use in concrete
Manufacturer	Hilti Aktiengesellschaft Feldkircherstrasse 100 9494 SCHAAN FÜRSTENTUM LIECHTENSTEIN
Manufacturing plant	Hilti Plants
This European Technical Assessment contains	21 pages including 3 annexes which form an integral part of this assessment
This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of	330499-02-0601, Edition 11/2023
This version replaces	ETA-18/0972 issued on 18 July 2023

Figure 7: ETA 18/0972 of HAS-D for static loading

Deutsches Institut für Bautechnik DIBt

Eine vom Bund und den Ländern gemeinsam getragene Anstalt des öffentlichen Rechts

Zulassungs- und Genehmigungsstelle für Bauprodukte und Bauarten

Datum: 19.03.2024 Geschäftszeichen: I 22-1.21.3-18/23

Allgemeine Bauartgenehmigung

Nummer: Z-21.3-2155

Geltungsdauer vom: 19. März 2024 bis: 19. März 2029

Antragsteller: Hilti Deutschland AG Hiltistraße 2 86916 Kaufering

Gegenstand dieses Bescheides: Injektionssystem Hilti HIT-HY 200 mit HAS-D zur Anwendung in Stahlfaserbeton unter ermüdungsrelevanter zyklischer Beanspruchung

Der oben genannte Regelungsgegenstand wird hiermit allgemein bauaufsichtlich genehmigt. Dieser Bescheid umfasst vier Seiten.

Figure 8: abG Z-21.3-2155 of HAS-D for fatigue loading

HUS4

The ETA-20/0867 for the Hilti screw anchor HUS4 (carbon steel version) has been updated in April 2024 to extend its assessment document for the use in SFRC with steel fibres Group I, up to a maximum content of 80 kg/m^3.


Deutsches Institut für Bautechnik DIBt

Public-law institution jointly founded by the federal states and the Federation

European Technical Assessment Body for construction products

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Designated according to Article 29 of Regulation (EU) No 305/2011 and member of EOTA (European Organisation for Technical Assessment)

European Technical Assessment **ETA-20/0867 of 25 April 2024**

English translation prepared by DIBt - Original version in German language

General Part

Technical Assessment Body issuing the European Technical Assessment:	Deutsches Institut für Bautechnik
Trade name of the construction product	Hilti screw anchor HUS4
Product family to which the construction product belongs	Mechanical fasteners for use in concrete
Manufacturer	Hilti AG Feldkirchenstraße 100 9494 Schaan FÜRSTENTUM LIECHTENSTEIN
Manufacturing plant	Hilti Werke
This European Technical Assessment contains	38 pages including 3 annexes which form an integral part of this assessment
This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of	EAD 330232-01-0601-v05, Edition 01/2024
This version replaces	ETA-20/0867 issued on 14 July 2022

Figure 9: ETA 20/0867 of Hilti screw anchor HUS4

The updated ETA covers static and seismic C1 loading conditions, but not seismic C2 loads when fastening is done in SFRC. In plain concrete, seismic loads are covered fully.

DESIGN EXAMPLE IN PROFIS ENGINEERING

Design in PROFIS Engineering

Following the recent ETA updates mentioned in the previous section, Hilti has also updated the PROFIS Engineering software to include SFRC as a new base material, which can be selected both in the standard and premium version. As a reminder, the standard license only covers rigid baseplates assumptions, while the premium version allows for more complex designs of steel connections to also consider the baseplate flexibility using Component-Based Finite Element Method (CBFEM).

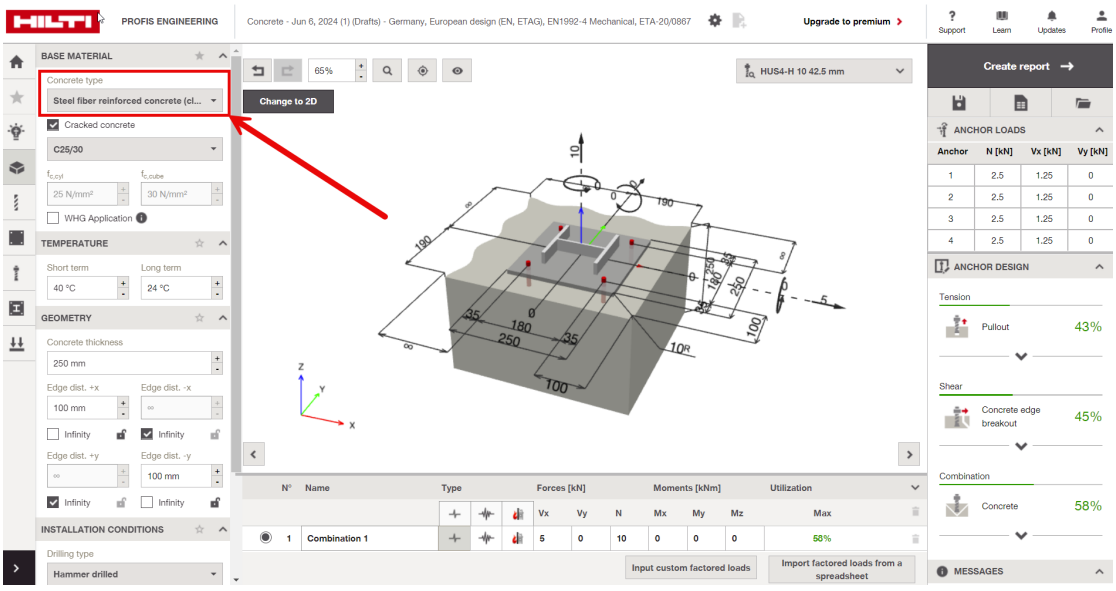
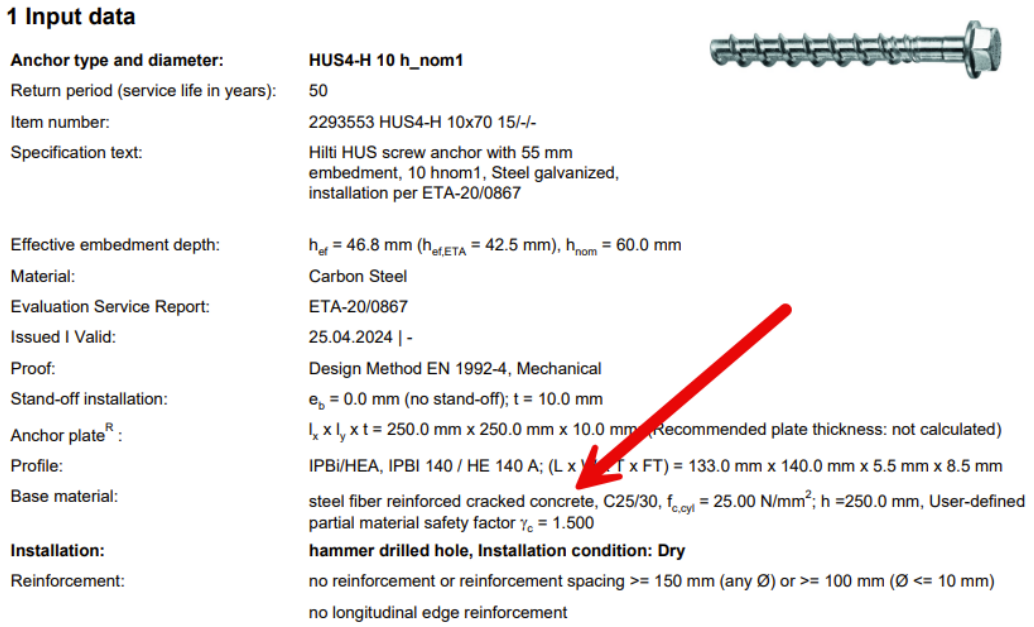


Figure 10: PROFIS Engineering covering SFRC.

The type of concrete can now be selected through a drop-down menu (see Fig. 10 above). The steel fibre-reinforced concrete covers both cracked or uncracked and has the same strength categories as normal concrete.

Report

The design report generated by PROFIS Engineering will also be adjusted for the cases when steel fibre-reinforced concrete is used. An example report is shown below with the changes highlighted in green.



1 Input data

Anchor type and diameter:	**HUS4-H 10 h_nom1**
Return period (service life in years):	50
Item number:	2293553 HUS4-H 10x70 15/-/-
Specification text:	Hilti HUS screw anchor with 55 mm embedment, 10 hnom1, Steel galvanized, installation per ETA-20/0867
Effective embedment depth:	h_{ef} = 46.8 mm ($h_{ef,ETA}$ = 42.5 mm), h_{nom} = 60.0 mm
Material:	Carbon Steel
Evaluation Service Report:	ETA-20/0867
Issued I Valid:	25.04.2024 | -
Proof:	Design Method EN 1992-4, Mechanical
Stand-off installation:	e_b = 0.0 mm (no stand-off); t = 10.0 mm
Anchor plate^R :	l_x x l_y x t = 250.0 mm x 250.0 mm x 10.0 mm; (Recommended plate thickness: not calculated)
Profile:	IPBi/HEA, IPBl 140 / HE 140 A; (L x W x T x FT) = 133.0 mm x 140.0 mm x 5.5 mm x 8.5 mm
Base material:	steel fiber reinforced cracked concrete, C25/30, $f_{c,cyl}$ = 25.00 N/mm^2; h =250.0 mm, User-defined partial material safety factor γ_c = 1.500
Installation:	**hammer drilled hole, Installation condition: Dry**
Reinforcement:	no reinforcement or reinforcement spacing >= 150 mm (any Ø) or >= 100 mm (Ø <= 10 mm)
	no longitudinal edge reinforcement

Figure 11: PROFIS Engineering report highlights the use of SFRC as a base material.

CONCLUSION

In conclusion, the historical evolution of building materials has led to the current trend of utilizing steel fibre-reinforced concrete (SFRC) in construction and using this type of specialized concrete is becoming more and more common. SFRC offers several advantages over traditional concrete, including increased tensile strength and enhanced resistance to cracking, fatigue, impact, and abrasion. For these reasons, the use of SFRC in the construction business is steadily growing.

On the other hand, the lack of anchoring solutions with an ETA for fastening in SFRC has been a challenge for those applications which need to be designed according to Eurocode regulations.

Hilti comes today with new ETA updates for HAS-D with injection mortar HIT HY200-A, -R, -A V3 and -R V3, and for HUS4.

Based on the ETAs 18/0972 and 20/0867 the design of these anchoring solutions in SFRC can be done according to the EN1992-4.

Hilti solutions approved for use in SFRC will be selectable in PROFIS Engineering, to allow the user to easily identify and design the relevant anchor families in a quick and efficient way.

REFERENCES

[1] EN 1992-4:2018, Eurocode 2: Design of concrete structures – Part 4: Design of fastenings for use in concrete, 2018.

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[3] EAD 330232-01-0601: Mechanical fasteners for use in concrete, Brussels: EOTA, 2019.

[4] B. B. A. S. Mate Toth, Anchorage in steel fiber reinforced concrete – concept, experimental evidence and design recommendations for concrete cone and concrete edge breakout failure modes., Stuttgart: Institute of Construction Materials, University of Stuttgart, 2019.

[5] M. T. A. S. Boglarka Bokor, Influence of steel fiber content on the load-bearing capacity of anchorages in concrete., Stuttgart: 3rd international Symposium on Connections between steel and concrete., 2017.

[6] EN 14889-1 – 2007 – Fibres for concrete, Part 1: Steel fibres - Definitions, specifications and conformity, 2007.

[7] ETA-18/0972: Injection system Hilti HIT-HY 200-A, HIT-HY 200-R, HIT-HY 200-A V3 and HIT-HY 200-R V3 with HAS-D, Berlin: DIBt, 2023.

[8] abG Z-21.3-2155: Injektionssystem Hilti HIT-HY 200 mit HAS-D zur Anwendung in Stahlfaserbeton unter ermüdungsrelevanter zyklischer Beanspruchung, Berlin: DIBt, 2024.

[9] ETA-20/0867: Hilti screw anchor HUS4. Mechanical fasteners for use in concrete, Berlin: DIBt, 2024.

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

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