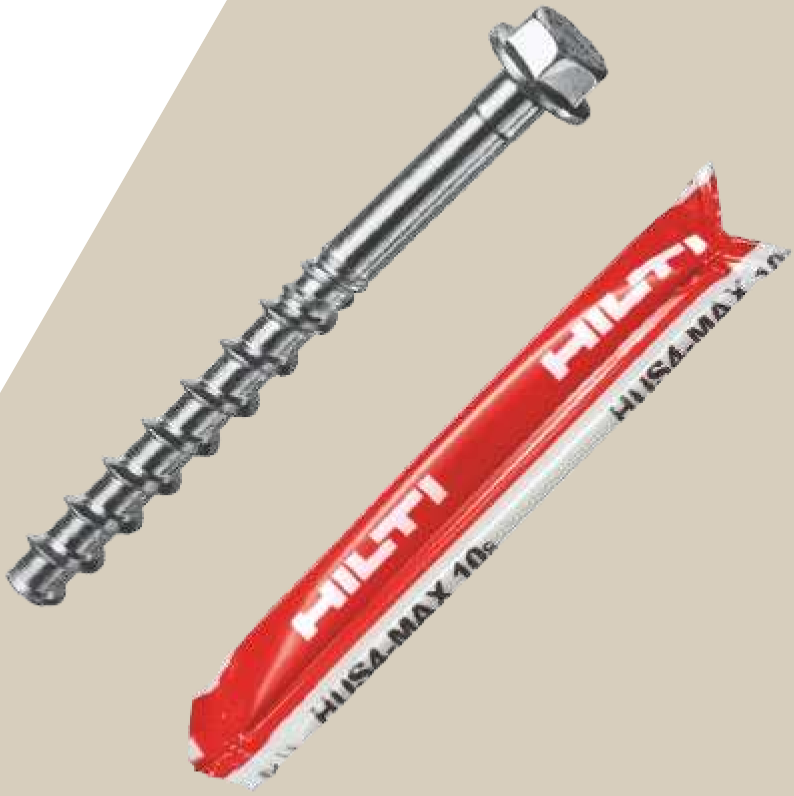
POST-INSTALLED BONDED SCREW ANCHOR, AN INNOVATIVE TECHNOLOGY

Advantages, Application and Design



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1. INTRODUCTION

Fastening technology is becoming increasingly important in civil structural engineering worldwide, seeing widespread use in connecting a large variety of structural and non-structural components. Anchors can be grouped into cast-in mechanical, post-installed mechanical, or post-installed bonded systems, with the choice of system depending upon a specific application’s load and durability demands. Appropriate selection, design and on-site execution of post-installed anchors becomes crucial to help mitigate the risk of accidents or structural failures that may cause damage to life, property or equipment. At Hilti, we aim to combine better specifications and jobsite practices. For the engineer, our solutions help make specifications higher performing and value engineered while, for the contractor, they help make jobsite practices faster, simpler, safer and more sustainable. Drawing many years’ expertise and a passion for innovation, we are excited to share our latest innovation and technology.

This article presents a novel technology for anchoring in post-installed steel-to-concrete fastenings: the **bonded screw anchor Hilti HUS4-MAX.** This hybrid anchor system utilizes the properties of both mechanical and bonded anchors, where the mechanical component is a Hilti HUS4 concrete screw and the bonded component is a Hilti HUS4-MAX capsule (polymer resin, hardener and aggregates in a defined mix ratio)**.** This article describes the working principle of hybrid anchors (Chapter 3), the regulatory framework and qualification as per EAD 332795 [1] (Chapter 4), detailed design methods according to latest EOTA TR 075 [2] in collaboration with EN 1992-4 [3] (Chapter 5), design examples (using PROFIS Engineering software) (Chapter 6), and advantages of bonded screw anchors for various applications (Chapter 7).

The article provides guidance to engineers involved in designing post-installed bonded screw anchors for steel-to-concrete fastenings. Furthermore, it is also useful for contractors and their in-house technical teams, as well as others who are directly or indirectly associated with such fastening applications.

Fig. 1.1: HUS4-MAX for steel-to-concrete baseplate application

2. POST-INSTALLED ANCHORS – THE ADVANTAGE OF A COMBINED SYSTEM

2.1 Post-installed mechanical and bonded anchors

The load-transfer mechanisms for various fastening systems are typically identified as **mechanical interlock**, **friction** and **adhesive bond** mechanisms. Post-installed anchors transfer load from the baseplate to the concrete through different working principles. They may be broadly classified as **mechanical** and **bonded** anchors. Mechanical anchors derive their strength from principles like friction and keying between steel and concrete. On the other hand, bonded anchors derive their strength from the bond along the interfaces between steel-adhesive and adhesive-concrete.

The first category includes expansion anchors (e.g. Hilti HST3), drop-in anchors (e.g. Hilti HKD), undercut anchors (e.g. Hilti HDA) and concrete screws (e.g. Hilti HUS4). The second one includes capsule anchor systems (e.g. Hilti HVU2) and injection systems (e.g. Hilti HIT-RE 500 V4). Given the large variety of anchor systems available on the market today, design or installation professionals may find it difficult to select the appropriate anchor for a specific application. The most appropriate fastening system should be selected by considering jobsite and construction conditions, since individual systems have inherently different characteristics, advantages and drawbacks depending on the application requirements.

2.2 Difference between post-installed mechanical and bonded anchors

The main criteria to consider before choosing between post-installed mechanical and bonded anchors (depending on the jobsite requirement and design conditions) are shown in Table 2.1.

Table 2.1: Key points for proper selection of anchors

	Mechanical anchor	Chemical anchor
Working principle	Mechanical interlock or friction	Bonding
Anchor loading conditions	Immediately	Require certain curing time to be loaded fully
Edge and spacing requirement	Large edge and spacing distance (except screw and undercut fasteners)	Suitable for smaller edge and spacing distances
Base material condition	Strong and stable base material that can withstand the installation forces	Suitable also for low-strength base material
Hole cleaning	Less sensitive to intensity of hole cleaning	More sensitive to intensity of hole cleaning
Water tightness	Not fit for use in water-filled concrete	Water tightness is ensured by some approved systems
Embedment depth	Limited variation in embedment depths	Flexibility of embedment including larger and variable embedments
Installation and in-service temperature	Not relevant	More sensitive to high temperature
Creep behavior	Not relevant	Significant effect due to sustained load

Due to the contrasting advantages and drawbacks of mechanical and chemical anchors, there is a demand for an anchoring technology which can combine the benefits of both mechanical and chemical anchors, i.e. the latter's higher performance in terms of load resistance, edge distance and spacing, with the former's installation simplicity and productivity.

Hilti bonded screw anchors, obtained by combining HUS4 screws with HUS4-MAX chemical capsules, achieve this because they benefit from the dual action of both mechanical undercutting and the effect of chemical technologies through a hybrid solution.

3. BONDED SCREW ANCHOR HUS4-MAX

The bonded screw anchor HUS4-MAX is a hybrid system that uses a concrete screw (anchoring system based on mechanical interlock or undercut) and a chemical system (anchoring based on adhesion and micro-keying). The bonded screw anchoring system employs a concrete screw alongside a foil capsule filled with two components bonding material. The capsule contains a polymer resin, hardener and aggregates in a defined mix ratio. The mechanical screw element helps to create a secure hold within concrete, whereas the adhesive component surrounding the screw enhances the anchor's stability and load bearing capacity.

3.1 Understanding the bonded screw system

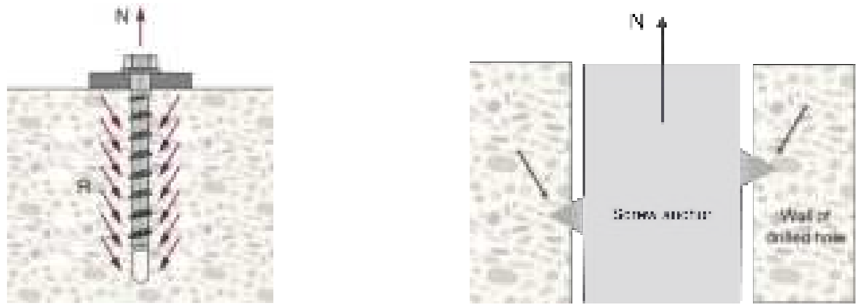
To enable a better understanding of the bonded screw anchor and the benefits of combining mechanical bonded anchors, the following situation can be observed: if the polymer/mortar was completely removed, the residual anchoring system would be a pure concrete screw transferring the load by mechanical interlock via the thread cut into the walls of the borehole (Fig. 3.1). Conversely, the conditions which negatively influence the bond behavior, for example borehole cleaning, temperature of the base material, sustained loads, etc. are mitigated by the concrete screw. On the other hand, the load carrying behavior of the screw anchor is dependent on the borehole tolerances, which may weaken the interlock mechanism, especially when concrete is cracked in instances such as seismic conditions. This sensitivity is reduced by the presence of the adhesive mortars between the threads. The Hilti HUS4 screw used with a HUS4-MAX capsule is not as sensitive to the unfavorable parameters which are in general valid for bonded and screw anchor systems. However, this is only possible if the combination of thread geometry and characteristics of the adhesives are balanced as exemplified by the Hilti HUS4 screw with HUS4-MAX capsule and validated by the qualification tests as per EAD 332795 [1] (see Section 4).

a) HUS4 screw anchor with HUS4-MAX capsule

b) HUS4 screw in concrete after removal of mortar

Fig. 3.1: Condition assuming removal of mortar from HUS4-MAX anchor

If only the mechanical HUS4 screw anchor is embedded in concrete, the load transfer occurs as shown in Fig. 3.2. The screw transfers the load to the concrete through the mechanical interaction between its threads and the concrete. The thread portion of screw is more vulnerable due to stress concentration at the tip. The load-carrying mechanism is based on the balancing of external tension force, N, with the local bearing pressure between the threads and the concrete, R, along the embedment.



a) HUS4 anchor under tension load b) Enlarged view of interaction between threads and concrete

Fig. 3.2: Load transfer mechanism for HUS4 screw anchor

The use of capsule HUS4-MAX with the screw helps to distribute the stress through a bond mechanism and can provide better resistance than only a screw anchor. Hence, the HUS4-MAX anchors can help mitigate the risk of generating peak stress in threads and variables affecting mechanical behavior, such as concrete quality.

3.2 How to install HUS4-MAX system

The Hilti HUS4-MAX is installed in the following way:

Preparation: a hole of the appropriate size and depth is drilled into the base material by hammer drilling using a suitable drill bit.

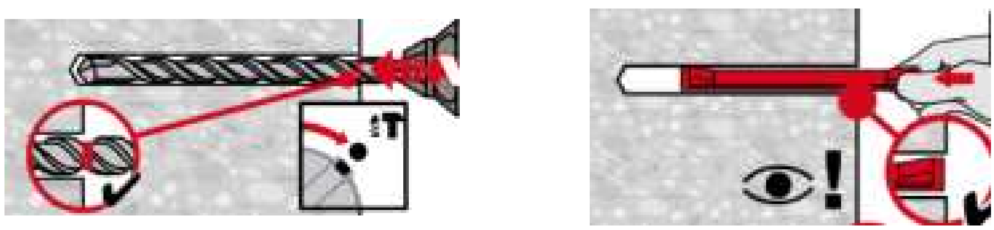
Placing of capsule: the HUS4-MAX capsule is placed in the drilled hole.

Insertion: the anchor is then inserted into the drilled hole using an impact screwdriver. When driving the concrete screw into the hole, the foil capsule is shredded but also compressed.

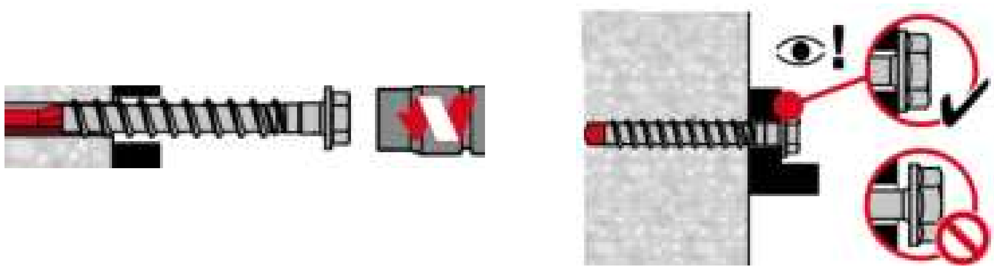
The resin hardener and aggregates are mixed and the annular gap around the concrete screw and the thread cut into the wall is filled with the polymer matrix, also filling eventual cracks in the concrete. The quantity of the polymer materials in the foil capsule is specifically selected to fill the borehole without pouring out.

Chemical bonding: the resin capsule bonds with the surrounding material, enhancing the anchor's resistance and stability.

Note: Please refer to Instructions for use (IFU) for more details regarding installation



a) Drilling of borehole b) Placing of HUS4-MAX capsule



c) Insertion of screws d) HUS4-MAX is installed

Fig. 3.3: Installation of HUS4 MAX anchor with capsule

4. REGULATORY FRAMEWORK AND QUALIFICATION

The qualification of post-installed anchors refers to the process of evaluating their performance and suitability for a specific application. The qualification of anchors depends on multiple steps/processes: manufacturer's documentation, third-party testing, quality control and environmental considerations. The essential characteristics of the product are included in the European Technical Assessment (ETA) and used in the design as per EN 1992-4 [3] or the applicable Technical Report (TR) issued by the European Organization for Technical Assessment (EOTA). The qualification of post-installed anchors described in this chapter is based on EOTA EADs.

Since bonded screw anchors function differently to purely mechanical or bonded systems, they can neither be assessed according to EAD 330499 [4], used to assess chemical anchors, because the external thread diameter of the steel element is larger than the drill hole diameter, nor according to EAD 330232 [5], which deals with the assessment of mechanical anchors due to differences in specific essential characteristics such as combined pull-out and concrete failure and influence of sustained load ψ_{sus}^{0}. Therefore, this requires a new qualification process and a specific design method.

The new EAD 332795 [1] has been introduced to cover the assessment of post-installed bonded screw anchors. The assessment criteria (Table 4.1) for a bonded screw anchor considers robustness aspects relevant for mechanical and bonded anchors. The performance is based on the concrete, screw performance and mortar combination.

Table 4.1: Different parameters covered in EAD 332795

Parameter	Description
Minimum diameter	6 mm
Minimum and maximum embedment depth	≥ 40 mm and $\leq 20d_0$
Installation temperature	-40°C to +40°C
Design working life	50 years
Base material	Concrete strength C20/25 to C50/60
	Uncracked and cracked concrete
Minimum thickness of base material	$h = max(1.5 \cdot h_{ef}, 80\ mm)$ and $h \geq (h_1 + \Delta h)$
Sensitivity to installation conditions	Drilling method
	Drill hole cleaning
	Installation direction (vertical downward/upward and horizontal)
	Minimum edge distance and spacing
	Minimum curing time
Environmental conditions	Freeze and thaw cycles
	In-service temperature
	High alkalinity and sulfurous atmosphere
	Hydrogen embrittlement
Loading types	Sustained load
	Seismic category C1 and C2
Characteristic displacements	Values for short- and long-term loadings

In the new EAD 332795 [1], the contributions of a mechanical concrete screw as per EAD 330232 [5] and bonding material as per EAD 330499 [4] are considered and the combined effect is assessed. The test program contained within allows a detailed assessment of the essential characteristics of the product for all the potential failure modes, which are then published in the ETA of the related product. A fire resistance test is carried out and designed in a way that only the contribution of mechanical part is considered. The contribution of bond material is negligible and steel failure is decisive. Hence, EAD does not foresee the possibility to test the contribution of bond material.

The presence of bonding material can compensate for the potential wear of the screw thread at the tip after installation, ensuring the load transfer now occurs at the deepest embedment point, which is different to simple concrete screws, for which the effective embedment depth is usually reduced following the provisions of EN 1992-4 [3]. To verify this, tests must be performed to check if the effective embedment depth used for the calculations of the concrete cone capacity (and related failure modes) can be considered equal to the nominal embedment of the fastener (usually the full length of the fastener) or if an intermediate value between the nominal one and the reduced embedment defined for concrete screws should be considered.

Table 4.2: Essential characteristics and qualification criteria in EADs

Load	Essential characteristic	Technical parameters	Mechanical anchors	Bonded screw anchors	Bonded anchors
Relevant EAD			**EAD 330232**	**EAD 332795**	**EAD 330499**
Static / quasi static	**Concrete pull-out / combined failure**	Characteristic resistance, concrete influence, sustained load	$N_{Rk,p}$, ψ_c	$N_{Rk,p,ucr/cr}$, ψ_c, ψ^0_{sus}	τ_{Rk}, τ_{Rk100}, ψ^0_{sus}
	Concrete cone failure	Effective embedment	$h_{ef} = 0.85\,(h_{nom} - 0.5h_t - h_s) \leq 8d_0$	$h_{ef} = 0.85\,(h_{nom} - 0.5h_t - h_s) \leq 8d_0$	$h_{ef} = h_{nom}$
Installation		Minimum concrete member thickness	$h_{min} \geq max(80\ mm, 1.5h_{ef}$ or $2h_{ef})$	$h_{min} \geq max(80\ mm, 1.5h_{ef}$ or $2h_{ef}, h_1 + \Delta h)$	$h_{min} \geq max(100\ mm, h_{ef} + \Delta h)$
		Temperature range	T1 (-40°C to +80°C)	T1 (-40°C to +40°C)	T1 (-40°C to +40°C)
Sensitivity to installation		Curing time	Not required	Required to be tested, however, it can be set zero if tests are performed immediately after setting	varies depending on the bonding material
Seismic	**Pull-out / combined failure C1/C2**	Characteristic resistance, concrete influence, sustained load	$N_{Rk,p,eq}$	$N_{Rk,p,ucr/cr,eq}$	$\tau_{Rk,eq}$, ψ^0_{sus}
Fire	**Pull-out or combined failure**	Characteristic resistance R30 to R120	$N_{Rk,p,fi}$	$N_{Rk,p,CS,fi}$	$\tau_{Rk,fi}$, $\psi^0_{sus,fire}$

5. DESIGN METHOD AS PER EN 1992-4 AND EOTA TR 075

5.1 Design verification against static loading as per EN 1992-4

Design verifications in EN 1992-4 [3] for static tension and shear loads are defined separately considering all relevant failure modes for post-installed anchors. In general, the calculation of resistances for bonded screw anchors against failure modes except combined pull-out and concrete cone follow the equations given in EN 1992-4 [3]. The design criteria against pull-out failure for mechanical anchors and combined pull-out and concrete cone failure for bonded anchors are separately defined.

Pull-out resistance of mechanical screw anchors: the characteristic resistance for mechanical screw anchors $\left(N^0_{Rk,p}\right)$ is considered from the product relevant ETA.

Combined pull-out and concrete cone resistance of bonded anchors: the equations of EN 1992-4 [3], which define the characteristic resistance to this failure mode for bonded anchors, use the characteristic bond strength (τ_{Rk}) as the main input for determining the characteristic tensile resistance $\left(N^0_{Rk,p}\right)$ of the anchor.

However, EN 1992-4 [3] does not provide design instructions against combined pull-out and concrete cone failure specific to bonded screw anchors. For this reason, a new Technical Report issued by EOTA, the TR 075 [2], has been developed. This document provides the necessary adaptations of the design method proposed in the EN 1992-4 [3], according to the new parameters defined and assessed via the EAD 332795 [1].

The summary of design resistances for each failure mode is defined in Table 5.1 and Table 5.2.

Table 5.1: Design scope in EN 1992-4 against tension loading

Failure mode	Scope in EN 1992-4	Remarks
Steel failure of anchor	$N_{Rk,s}$ value is given in the relevant ETA.	
Concrete cone failure	$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N}$	
Combined concrete cone and pull-out failure	Mechanical anchors: $N_{Rk,p}$ (taken from the relevant ETA) Bonded anchors: $N_{Rk,p} = N^0_{Rk,p} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \psi_{g,NP} \cdot \psi_{s,NP} \cdot \psi_{re,N} \cdot \psi_{ec,NP}$	No clear definition for bonded screw anchor is given in EN 1992-4. Refer to EOTA TR 075 for updated design considerations

Table 5.2: Design scope in EN 1992-4 against shear loading

Failure mode	Scope in EN 1992-4	Remarks
Steel failure of anchor without lever arm	$V_{Rk,s}$ value is given in the relevant ETA.	
Concrete pry-out failure	Mechanical anchor: $V_{Rk,cp} = k_8 \cdot N_{Rk,c}$	$N_{Rk,p}$ for bonded screw anchor is considered only for mechanical screw part
Concrete edge failure	$V_{Rk,c} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{\alpha,V} \cdot \psi_{h,v} \cdot \psi_{s,V} \cdot \psi_{ec,V} \cdot \psi_{re,V}$	

5.2 Combined pull-out and concrete cone failure as per EOTA TR 075

The resistance against combined pull-out and concrete cone failure for bonded screw anchors is detailed in EOTA TR 075 [2] and depends on the resistance of screw anchor as well as the property of bonding material.

The combined resistance: the characteristic combined pull-out and concrete cone resistance, $N_{Rk,p,ucr/cr}$ for a group of bonded screw anchors is derived by calculating the resistance values of the screw anchor and bonding element separately and then the group effect is considered by combining the two:

$N_{Rk,p,ucr/cr} = N_{Rk,p.CS.ucr/cr} + \alpha_b \cdot N_{Rk,p,B,ucr/cr}$ EOTA TR 075, eqs. (1) and (12)

$\alpha_b = 1 - \left(1 - \varphi_{b,ucr/cr}\right) \cdot \left(s_{cr,Np} - s\right)/s_{cr,Np} \leq 1$ EOTA TR 075, eqs. (3) and (13)

The resistance of the mechanical part (screw element) is defined by $N_{Rk,p.CS.ucr/cr}$ and the resistance of the chemical part (bonding element) is defined by $N_{Rk,p,B,ucr/cr}$. Both resistances are combined using a factor, $\varphi_{b,ucr/cr}$ to consider the contribution of bond property of bond material for uncracked/cracked concrete.

Resistance of screw anchor: the characteristic resistance of single concrete screw, $N^0_{Rk,p,CS,ucr/cr}$ is taken from the relevant product ETA.

The resistance of the concrete screw part in a group of anchors is calculated by the following equation:

$N_{Rk,p,CS,ucr/cr} = n \cdot N^0_{Rk,p,CS,ucr/cr} \cdot \psi_{ec,Np,CS}$ EOTA TR 075, eqs. (2) and (15)

When a. different tension load acts on individual anchors in a group, the group effect is considered by the factor, $\psi_{ec,Np,CS} = \frac{1}{1+2\cdot(e_N/s)} \leq 1$ and e_N, s are calculated using the equations as mentioned in EN 1992-4 [3]. n is the number of anchors in a group.

Resistance of bonding element: the characteristic resistance of the bonding material $N^0_{Rk,p,b,ucr/cr}$ for a single anchor is taken from relevant product ETA.

The resistance of the bonding material in a group of anchors is calculated by the following equation:

$N_{Rk,p,B,ucr/cr} = N^0_{Rk,p,B,ucr/cr} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \psi_{sus} \cdot \psi_{g,Np} \cdot \psi_{s,Np} \cdot \psi_{re,N} \cdot \psi_{ec,Np}$ EOTA TR 075, eqs. (5) and (16)

Sustained load factor $\psi_{\mathrm{sus}} = 1.0 \quad for\ \alpha_{sus} \leq \psi^0_{\mathrm{sus}}$ EOTA TR 075 eqs. (6) and (17)

$\psi_{\mathrm{sus}} = (\psi^0_{\mathrm{sus}} - \alpha_{sus} + \varphi_{b,ucr/cr})/\varphi_{b,ucr/cr} \quad for\ \alpha_{sus} > \psi^0_{\mathrm{sus}}$ EOTA TR 075 eqs. (7) and (18)

ψ^0_{sus} is the factor which takes care of the effect of sustained load on the bond strength of anchors and is considered from the product relevant ETA.

The factor ($\varphi_{b,ucr/cr}$) for the contribution of bond property in uncracked/cracked concrete is calculated using the following equation and the value is ≤ 1.0.

$\varphi_{b,ucr/cr} = N^0_{Rk,p,B,ucr}/(N^0_{Rk,p,CS,ucr} + N^0_{Rk,p,B,ucr})$ EOTA TR 075, eqs. (4) and (14)

The group effect of closely spaced anchors is considered by $\psi_{g,Np}$ and calculated using the equation as follows:

$\psi_{g,Np} = \psi^0_{\mathrm{g,Np}} - \left(\frac{s}{s_{\mathrm{cr,Np}}}\right)^{0,5} \cdot \left(\psi^0_{\mathrm{g,Np}} - 1\right) \geq 1$ EOTA TR 075, eqs. (9) and (19)

$\psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right) \cdot \left(\frac{N^0_{Rk,p,B,ucr/cr}}{N_{Rk,c}}\right)^{1,5} \geq 1$ EOTA TR 075, eqs. (10) and (20)

$N_{Rk,c} = k_3 \cdot h_{ef}^{1,5} \cdot \sqrt{f_{ck}}$ EOTA TR 075, eqs. (11) and (21)

$k_3 = k_{\mathrm{ucr,N}} = 11.0$ and $k_3 = k_{\mathrm{cr,N}} = 7.7$

The characteristic spacing is determined using the equation: $s_{cr,Np} = 4.1 \cdot \left(\psi_{sus} \cdot \frac{d}{h_{ef}} \cdot (N^0_{Rk,p,CS,ucr,c20/25} + N^0_{Rk,p,B,ucr,c20/25})\right)^{0,5} \leq 3h_{ef}$ EOTA TR 075, eq. (8)

d is the nominal diameter of the concrete screw and $N^0_{Rk,p,CS,ucr,c20/25}$ and $N^0_{Rk,p,B,ucr,c20/25}$ are the characteristic resistances of the screw part and bond element for a single fastener in uncracked concrete of defined strength.

$A_{p,N}$ is the actual projected area and $A^0_{p,N}$ is the ideal projected area of concrete cone.

$\psi_{s,Np}$ considers the effect of edge distance for the anchors loaded in tension, $\psi_{re,N}$ is the factor which includes the effect of reinforcement located in concrete and $\psi_{ec,Np}$ considers the eccentricity of a load acting on a group of anchors.

5.3 Design verification against seismic loading

The design method for post-installed anchors under seismic loading as per EN 1992-4, Annex C is applicable. For combined pull-out and concrete failure, the resistance value is determined according to EN 1992-4, cl. 7.2.1.6 and EOTA TR 075, cl. 3.2 using the respective characteristic mechanical resistance of the concrete screw $N^0_{Rk,p,CS,C1}$ or $N^0_{Rk,p,CS,C2}$, the respective characteristic bond resistance $N^0_{Rk,p,B,C1}$ or $N^0_{Rk,p,B,C2}$ given in the relevant ETA.

5.4 Design verification against fire loading

The design method for post-installed anchors under fire exposure provided in EN 1992-4, Annex D is applicable. For fire resistance only the concrete screw capacity (without the contribution of the bond material) is considered. Instead of the combined pull-out and concrete failure, a pull-out verification according to EN 1992-4, section 7.2.1.5 as for mechanical anchors is performed. Regarding the verification of combined bond and concrete failure, the value of characteristic pull-out resistance of a concrete screw, $N_{Rk,p,CS,fi}$ should be taken from the relevant ETA. For determination of resistance against concrete cone failure, the effective anchorage depth is calculated according to EAD 330232, figure 1.14.

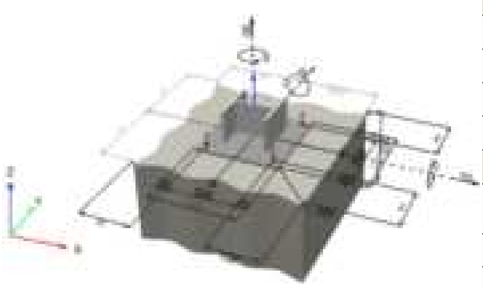
$$h_{ef} = 0.85\,(h_{nom} - 0.5h_t - h_s) \leq 8d_0$$

Note: in the case of HUS4-MAX, only the mechanical screw part contributes to the resistance against fire. If there is a specific requirement of using a bonded anchor in a project, HUS4-MAX delivers better performance under fire exposure and can be a suitable choice over most of conventional bonded anchor solutions.

6. DESIGN EXAMPLES

6.1 Design example against static loading

Project requirement: an I girder is connected to concrete wall using post-installed mechanical screw anchors. The 3D view of the applications is shown in Fig. 6.1.



Geometry	
Concrete thickness	250 mm
Baseplate	250x250x20 mm
I profile	IPBi 140/HE 140 A
Spacing between anchors	200 mm
Others	
Materials	Concrete C20/25
Design life	50 years
Installation	Rotary-hammer drilling / horizontal, dry

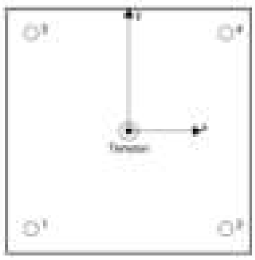
Fig. 6.1: Baseplate connection using post-installed anchors

Design loads and anchor properties:

Post-installed concrete screw anchors Hilti HUS4-H are used for connection. The details about design load and properties are given in Table 6.1.

Table 6.1: Design load and anchor properties

Anchor	N [kN]	Vx [kN]
1	7.5	2.5
2	7.5	2.5
3	7.5	2.5
4	7.5	2.5



Type of anchor	Mechanical	
Specification of anchor	HUS4-H	
Diameter of anchor	d	$10\ mm$
Effective embedment depth	h_{ef}	$64\ mm$
Nominal embedment depth	h_{nom}	$80\ mm$

Results:

The design has been checked in PROFIS Engineering software and the summary of utilization ratio is mentioned in Table 6.2.

Note: Design resistances are considered from ETA 18/1160 [6]

Table 6.2: Summary of utilization ratio using HUS4-H screw anchor

Failure mode in tension	Utilization [%]	Failure mode in shear	Utilization [%]
Steel	20	Steel	13
Concrete cone	59	Concrete pry-out	10
Combined pull-out	58	Concrete edge	49
Maximum utilization for combined action			**79**

Now, there is a requirement of retrofitting of the existing structure and design loads are modified as per revised design mentioned in Table 6.3.

Note: For retrofitting applications, German National approval [7] is followed

Table 6.3: Revised anchor loads and utilization ratios using existing HUS4-H anchors

Anchor	N [kN]	Vx [kN]	Vy [kN]
1	11.25	2.5	0
2	[illegible]	[illegible]	[illegible]
3	[illegible]	[illegible]	[illegible]
4	11.25	2.5	0

Failure in tension	[%]	Failure in shear	[%]
Steel	31	Steel	13
Concrete cone	89	Concrete pry-out	10
Concrete pull-out	87	Concrete edge	49
Maximum utilization for combined action			**116**

From the above table it is noted that the existing HUS4-H screw anchors are not suitable for the revised loads and the size needs to be increased to fulfil the design criteria. For the existing structure a possible solution is instead to add the HUS4-MAX capsule with the screw. This allows the use of the same borehole with a HUS4 screw and HUS4-MAX capsule, but increases the performance to a level suitable to the new load requirements. The design has been checked for HUS4-H screw anchors with HUS4-MAX capsule and the result is shown in Table 6.4.

Table 6.4: Summary of results using HUS4-MAX anchors of size d10 x 85 mm

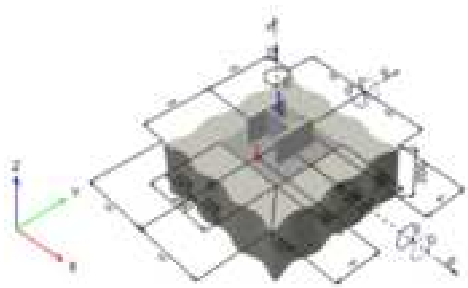
Failure mode in tension	Utilization [%]	Failure mode in shear	Utilization [%]
Steel	31	Steel	12
Concrete cone	79	Concrete pry-out	8
Combined pull-out and concrete cone	75	Concrete edge	48
Max utilization for combined action			**98**

The maximum utilization is within the allowable limit for the revised loads, hence the HUS4-MAX anchor is a suitable solution for this retrofitting application.

6.2 Design example against seismic loading

Project requirement:

A pipe support is connected to concrete slab using post-installed chemical anchors. The 3D view of the applications is shown in Fig. 6.2.



Geometry	
Concrete thickness	200 mm
Baseplate	250x250x20 mm
I profile	IPBi 140/HE 140 A
Spacing between anchors	180 mm
Others	
Materials	Concrete C20/25
Design life	50 years
Installation	Rotary-hammer drilling / horizontal, dry

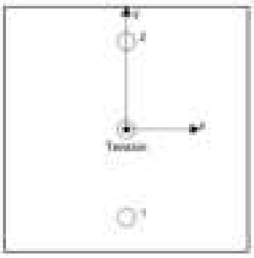
Fig. 6.2: Baseplate connection using post-installed chemical anchors

Design loads:

Design is checked for seismic C2-elastic design for the loads shown in Table 6.5. Post-installed chemical anchors Hilti HIT-HY 200-A V3+HAS-U are used for connection and the details are as follows:

Table 6.5: Design load and anchor properties

Anchor	N [kN]	Vx [kN]	Vy [kN]
1	[illegible]	[illegible]	[illegible]
2	[illegible]	[illegible]	[illegible]



Type of anchor	Chemical	
Specification of anchor	HIT-HY 200-A V3 + HAS U 8.8	
Diameter of anchor	d	$12\ mm$
Effective embedment depth	h_{ef}	$170\ mm$

Results:

The design has been checked in PROFIS Engineering software and the summary of utilization ratio is mentioned in Table 6.6.

Note: Design resistances are considered from ETA 18/1160 [6]

Table 6.6: Summary of utilization ratio using HIT-HY 200 A V3 chemical anchor

Failure mode in tension	Utilization [%]	Failure mode in shear	Utilization [%]
Steel	26	Steel	-
Concrete cone	45	Concrete pry-out	-
Combined pull-out and concrete cone	142	Concrete edge	-
Maximum utilization for combined action			**142**

HIT-HY 200-A V3 + HAS-U anchors of diameter 12 mm do not satisfy the design criteria against the seismic loads. The thickness of concrete is 200 mm and max allowable depth for HY 200 anchor is 170 mm. Since the depth of existing anchors can't be increased, the HY 200 anchor of size M12 cannot be used. The option to satisfy the design is to increase the diameter. An increased size of M16 x 110 mm can fulfil the design criteria (refer to Table 6.7). As an alternative option, the design has been checked using bonded screw anchors HUS4-MAX. A HUS4-MAX anchor of size d14 x 115 mm fulfils the design and the utilization ratios shown in Table 6.7.

Table 6.7: Summary of utilization ratio using HIT-HY 200 and HUS4-MAX

HIT-HY 200 (M16 x 110 mm)		HUS4-MAX (d14 x 115 mm)	
Failure mode in tension	**Utilization [%]**	**Failure mode in tension**	**Utilization [%]**
Steel	14	Steel	17
Concrete cone	75	Concrete cone	71
Combined pull-out and concrete cone	**99**	Combined pull-out and concrete cone	**96**

Note: The increased size for the HUS4-MAX hybrid system to satisfy the design is still smaller than the required size for HIT-HY 200 for the same embedment depth. Also, installation of HIT-HY 200 is more time consuming in comparison to the HUS4-MAX anchor system, which helps to reach a more optimized solution with simpler installation.

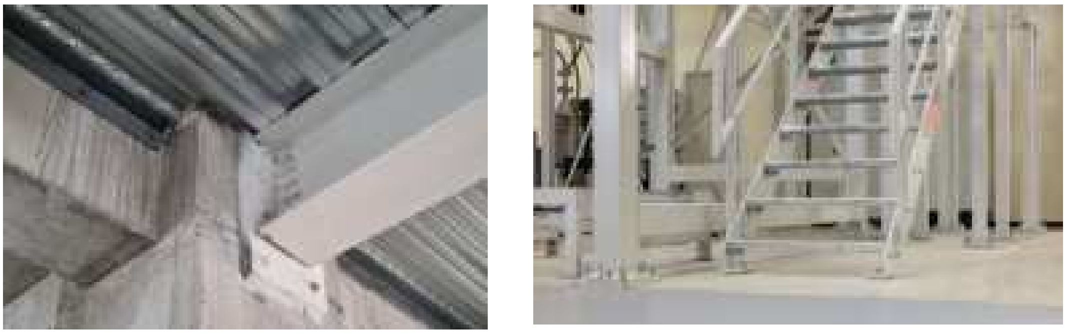
7. ADVANTAGES OF USING HUS4-MAX FOR SUITABLE APPLICATIONS

At Hilti, we combine better specifications and jobsite practices with our onsite support, helping to ensure that an application can be executed and installed as specified. The Hilti HUS4-MAX bonded screw anchor offers several advantages over many mechanical and bonded systems due to its characteristics:

- **High load capacity:** bonded screw anchors provide excellent load bearing capacity, additional fire resistance and immediate loading like mechanical anchors. These anchors are suitable for a variety of secondary structural and non-structural applications, in uncracked and cracked concrete (C20/25 to C50/60), under static and seismic loading, and when fire resistance is a requirement.
- **Quick and efficient installation:** installation is designed to be quick and straightforward, and requires less time compared to bonded anchors. This faster, simpler, safer installation – with no requirement for cleaning the drilled hole, minimal impact of jobsite temperatures in virtually all conditions, adjustability, and removability in case of wrong installation – helps increase productivity on the jobsite.
- **Optimized and code compliant solution:** an optimized, high performing and value engineered solution for the relevant applications, with small edge distances and spacing typical of a screw anchor, compliance with European standards, plus full integration in Hilti PROFIS Engineering software, ensures an efficient and accurate design process.

Hilti HUS4-MAX bonded screw anchors can be recommended for following applications:

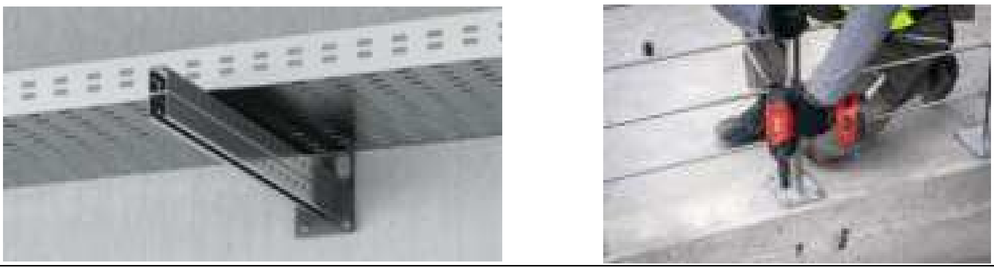
Primary and secondary structural connections: HUS4-Max is suitable in normal weight cracked and uncracked concrete (C20/25 to C50/60) under static, quasi-static and seismic (C1 / C2) loading. The highlight is provided by the double holding function (undercut and adhesion). Here are some examples showing application of HUS4-MAX anchors for medium to heavy duty applications in Fig. 7.1.



a) Column baseplate b) Steel staircase

Fig. 7.1: Examples of primary and secondary connections

Non-structural applications: even if the application is non-structural this does NOT mean there is NO safety relevance. The EOTA TR 075 [2] / EN1992-4 [3] is intended for safety related applications in which the failure of fastenings may result in collapse or partial collapse of the structure, which could cause risk to human life or lead to significant economic loss. In this context it also covers non-structural elements supported by, or attached to, new or existing buildings such as handrails, roofs and lightweight steel structures. For such applications the Hilti HUS4 screw and Hilti HUS4 bonded screw fastener provides you with the possibility of designing with the smallest edge and spacing distances as used with chemical anchors. In addition, even in connection with the mortar capsule, the Hilti HUS4 bonded screw fastener is still completely removable. Two examples of applications are shown in Fig. 7.2.



a) MT support for electrical b) Handrail fixing

Fig. 7.2: Examples of non-structural connections

Bonded screw anchor HUS4-MAX is also a preferable choice for the connection of building equipment, building systems and machineries due to its flexibility and ease of installation. The double holding function and removability when changing the position of the equipment provides the advantage of being more flexible against functional changes.

8. CONCLUSION

The concrete screw anchor Hilti HUS4 is the latest generation of the Hilti post-installed bonded concrete screw, which has been used in jobsites for temporary and permanent fastenings over many years. The latest Hilti HUS4 bonded screw fastener builds on this technology by pairing the screw with the HUS4-MAX foil capsule that leads to a high performing, value engineered, optimized design specification connected to faster, simpler, safer and sustainable installation.

It also provides greater flexibility to accommodate design changes: by adding the capsule, design challenges and limitations linked to one or the other technology can be addressed without compromising installation simplicity or productivity for the contractors on the jobsite.

The best of both worlds for designers and contractors ... brought to you by Hilti.

9. REFERENCES

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[6] ETA-18/1160: HUS4 Bonded screw, Bonded screw fastener for use in concrete, Berlin: DIBt, 16.01.2025.

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