BONDED SCREW FASTENER, A NEW CHEMICAL ANCHORING TECHNOLOGY

Hilti concrete srew HUS4 with Hilti capsule HUS4-MAX

Whitepaper for planners and structural engineers

CONTENT

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ABSTRACT

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Modern fastening technology is becoming increasingly important in civil structural engineering worldwide. Every fastening element is designed for optimal performance for a specific application. When a fastening element is used for an application for which it is not intended, its performance can be negatively affected. At Hilti, we are committed to bringing better, safer, and more reliable fastening system solutions to our designers and contractors. Drawing on over 80 years of expertise, and a passion for innovation, we're excited to announce our latest innovation yet:

A novel anchorage technology for designing and executing applications in concrete construction:

Hilti bonded screw fastener: Hilti HUS4 concrete screw with HUS4-MAX capsule

A new European assessment document EAD 332795 "Bonded screw fasteners for use in concrete" [1] was developed for this new fastening technology.
EAD 332795 [1] is instrumental to a design method in line with EC2, part 4 [2], and regulated through the additional provisions given in a Technical Report issued by EOTA, the EOTA TR 075 [3]. This document coordinates the design method in its general aspects, however for the technical approach it endorses sections of the Eurocode 2, part 4 [2]. All these aspects are brought together in this paper to provide an understanding about the working principal, the assessment process, the design process, and the advantages concerning applications of this new anchoring technology for your daily design.

GENERAL

02

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 solution. In general a distinction between mechanical anchors (expansion anchors e.g. Hilti HST 3, drop-in anchors e.g. Hilti HKD, undercut anchors e.g. Hilti HDA and concrete screws e.g. Hilti HUS3) and chemical anchors (e.g. capsule anchor systems Hilti HVU2 and injection systems e.g. Hilti HIT-RE 500 V4) can be made. Furthermore, there are no general pros or cons but only individual anchoring system characteristics that matter, as the fastening systems should be selected considering the jobsite and construction conditions.

Fig. 1 below provides roughly the main perceived differences between mechanical and chemical anchors.

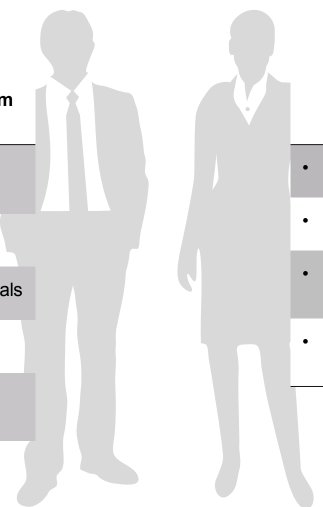
In general, the benefit of mechanical anchors is seen as to be much simpler to install compared to chemical anchors. In addition, mechanical anchors are also perceived as more economical although the edge and spacing distances are perceived as relatively large.

In contrary, the benefit of chemical anchors is clearly based on the perception that (1) these can also be installed in poor concrete quality without lacking performance, (2) they yield higher loads and (3) the mortar can protect the boreholes from humidity compared to mechanical anchoring systems. On the other hand, the installation process is perceived as much more complex due to the influence of environmental conditions like temperature, using of dispenser, cleaning effort etc.

Consequently, it can be said that there is a demand for an anchoring technology combining the benefits – as much as possible of both anchoring technologies – mechanical anchors, and chemical anchors.

The Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) does just that, coming along with a new European design concept and a new European assessment process.

Mechanical anchoring system	Chemical anchoring system
• Immediately ready for loading	• Curing time required
• Water can enter the hole	• Hole is filled with mortar
• Limited base materials	• Wider range of base materials
• Less flexibility in length	• Total flexibility
• Large edge and spacing distances	• Small edge and spacing distances
• Simple installation process	• More effort to install



Mechanical anchoring system	Chemical anchoring system
• No shelf life	• Shelf life
• Limited loads	• Highest loads
• Non sensitivity to temperature	• Sensitivity to temperature
• Requires a certain concrete quality	• Improves low concrete quality

Fig. 1 Perceived characteristics of mechanical vs. chemical anchoring systems

WHAT IF

we could create an even better chemcial anchoring system?

03

The Hilti HUS4 bonded screw fastener

does just that!

The new European assessment document EAD 332795 for "bonded screw fasteners for use in concrete" allows for the qualification of the new technology which maybe denominated as a hybrid between 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 with a hexagonal head or outer thread in conjunction with a foil capsule filled with the constituent bonding materials or an injection system, **see Fig. 2**.

For example, the new Hilti HUS4-MAX is delivered in conjunction with foil capsules. In such a case the capsule contains polymer resin, hardener, and aggregates in a defined mix ratio. A foil capsule is placed in a drilled hole, where the drilled hole could have been produced by hammer drilling or diamond core drilling. The concrete screw is driven through the capsule. When driving the concrete screw into the hole the foil capsule is likewise shredded but also compressed, the resin hardener, aggregates are mixed and the annular gap around the concrete screw and the thread cut into the wall is filled with the polymer matrix, simultaneously cracks around the anchor are filled with resin, **see Fig. 3**.

The bonded screw fastener load transfer mechanism is based on mechanical interlock, friction, and chemical interlock. Compared to conventional bonded anchors one additional load transfer mechanism is added, mechanical interlock. Consequently, a perfect bond, undercut and friction quality can be concluded.

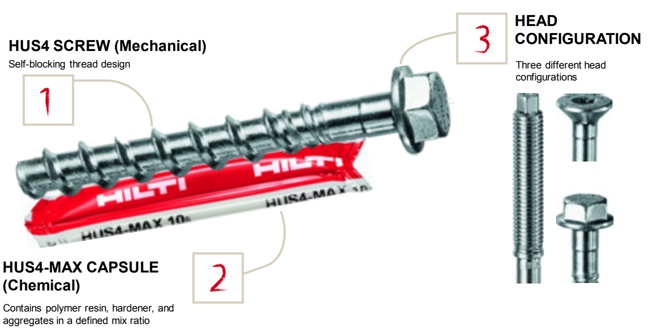


Fig. 2 Hilti HUS4 bonded screw fastener

What is happening in the borehole?

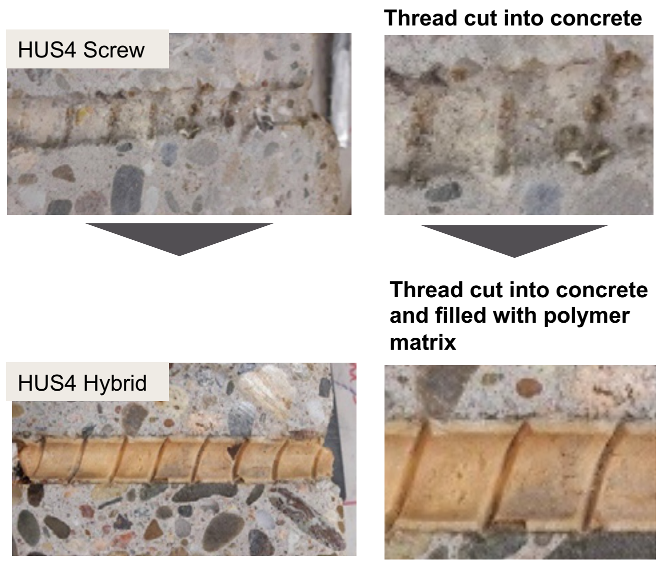


Fig. 3 Load trasnfer mechnism of Hilti HUS4 and Hilti HUS4 MAX capsule

WHAT IF

we could create a chemical system nearly independent from environmental conditions?

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3.1 An intellectual game for understanding the bonded screw fastener

To have an idea about the bonded screw anchor and why this anchoring technology is the most reliable chemical anchoring system, the following intellectual game can be played:

If the polymer would be completely removed, we have still a portion of mechanical interlock, see Fig. 4 compared to a normal threaded rod as given by standard bonded anchor systems. Consequently, it can be said that conditions influencing the bond behavior are absorbed by mechanical interlock, these are borehole conditions like cleaned vs. uncleaned boreholes, drilling process (hammer drilling vs. diamond coring), temperature of the base material and the long-term behavior of the mortar type. This being said, qualification tests with Hilti HUS4 bonded screw fastener underline that this system is less to zero influenced by the parameters which are in general valid for bonded anchors systems, only.

Of course, this statement is only true, if the combination of thread geometry and characteristics of the adhesives are balances as provided with Hilti HUS4 bonded screw fastener. Other systems with reduced interlock in favor of higher bond provided by the chemical, are assumed to show higher sensitivities comparable with a fully bonded threaded rod.

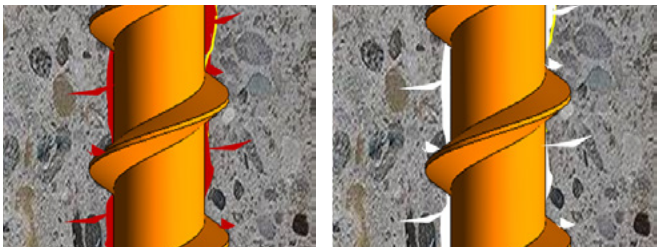

Fig. 4 Separating the simultaneously acting load transfer mechanism

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A safe anchorage requires not only detailed planning and design but also the consideration that the anchor systems performs reliable under ordinary and adverse job-site conditions. In Europe, to fulfil such an objective, the performance and characteristics of a construction product are evaluated based on the qualification requirements included in a European Assessment Document (EAD) issued by European Organization for Technical Assessment (EOTA). With the new fastening technology "bonded screw anchors" a new qualification procedure and a specific design method are provided to the engineering community.

A comparison between the new assessment procedure for bonded screw anchors and the pre-existing, well-established EAD for chemical anchors is briefly presented in the following. As the bonded screw can be denominated as a hybrid system between a concrete screw and a chemical system, the system cannot be assessed according to other existing EADs, since an assessment method to cover various ranges of combination of both functioning principles is needed.
Consequently, the assessment for bonded screw anchors includes aspects of verification related to the mechanical functioning of the concrete screw EAD 330232 [4] as well as to the chemical strength and durability of the used mortar type EAD 330499 [5].

4.1 Qualification of bonded screw fasteners for use in concrete

The European Assessment Document EAD 332795 [1] provides testing requirements and assessment criteria intended to verify the suitability of a system, to specify the admissible conditions of use (e.g. loading type, environmental exposure among others) and ultimately to determine the characteristics of performance (i.e. resistance of the anchor) which are needed for the design of a fastening point. The outcomes of the evaluation with all relevant parameters for the construction product are then published in a European Technical Assessment (ETA), as usually foreseen by the EOTA CE-marking path.

The structure of the new assessment document is similar to those of EAD 330232 [4] (mechanical fasteners) and EAD 330499 [5] (bonded fasteners). The conduction of the required test program allows to derive in detail the essential characteristics of the product for all the potential failure modes to be found in the European Technical Assessment (ETA) of the related product.
The main element of novelty in the EAD 332795 [1] for bonded screw fasteners is the assessment of the failure mode combined pull-out and concrete failure. It starts from the definition of the baseline tension resistance of the bonded screw fastener. Afterwards, several sensitivity and robustness tests provide a verification of the mechanical response of the entire system. In addition, to complete the assessment of the combined pullout and concrete resistance, a qualification of the sensitivities and durability of the bonding material itself must be realized. These tests are conducted with the condition of fastener diameter and embedment depth, that is identified having the largest contribution to performance from the bonding material in uncracked concrete. This is evaluated through a comparison between the basic resistance of the bonded screw fastener with that of the same screw installed without the bonding material.

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With regards to the parameters for concrete cone resistance, it is considered that the presence of bonding material can compensate the potential wear of the screw thread at the tip after installation ensuring the load transfer to occur at the deepest embedment point. To verify this, tests are performed to verify the effective embedment depth to be used for the calculations of the concrete cone capacity (and related failure modes). This depth maybe equal to the nominal embedment of the fastener. Values of effective embedment depth between the nominal embedment and the equation of hef for concrete screws may also be assessed.

The resistance against hydrogen embrittlement and the anchor capacity under shear loading, are carried out following the same protocols of EAD 330232 [4] (mechanical fasteners).

The seismic assessment of bonded screw fasteners for the categories C1 and C2 is conducted in accordance with the existing requirements regulating mechanical and chemical anchors. It should be noted that the performance of the bonded screw fasteners under fire exposure may be taken from the resistance of the concrete screw without bonding material.

Table 1 provides an overview about the main technical parameters and how these are considered in the different EAD process. Due to the combination as hybrid system, the bonded screw fastener must also be assessed concerning sustained loading (creep behavior under sustained stress) and behavior temperature range.

Essential characteristic	Technical parameter	Bonded screw fasteners – EAD 332795	Bonded fasteners – EAD 330499
Static/quasi-static resistance to pullout or combined failure	Characteristic resistance, concrete influence, sustained load	$N'_{Rk,p}$ [kN]; Ψ_c , Ψ^0_{sus}[-]	τ_{Rk} and/or $\tau_{Rk,100}$ [N/mm²], Ψ^0_{sus} [-]
	Curing time	Yes / No	Yes
	Temperature range	I (40°C), II (80°C), III (120°C)	I (40°C), II (80°C), III (120°C)
Static/quasi-static resistance to concrete cone failure	Effective embedment	$0{,}85\ (h_{nom}-0{,}5h_t-h_s) \leq h_{ef} \leq h_{nom}$	$h_{ef} = h_{nom}$
Installation	Minimum concrete member thickness	h_{min} (≥ max (80mm, 1,5h_{ef} or 2h_{ef}, $h_1 + \Delta h$) [mm]	h_{min} (≥ max (100mm, $h_{ef} + \Delta h$) [mm]
Seismic resistance to pullout or combined failure C1/C2	Characteristic resistance, concrete influence, sustained load	$N_{Rk,p,eq}$ [kN]; Ψ^0_{sus}[-]	$\tau_{Rk,eq}$ [N/mm²], Ψ^0_{sus} [-]
Fire resistance to pullout or combined failure	Characteristic resistance R90, R120	$N_{Rk,p,fi}$ [kN] (same value of concrete screw)	-

Table 1 Comparison of technical parameters as considered in the related EAD

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4.2 The new design concept for bonded screw fasteners

EC2, Part 4 [2] applies for fastening in concrete using anchors carrying an ETA as the anchor parameters for calculating the resistance must be obtained from the respective assessment document. The respective assessment document specifies which design code and/or technical report must be followed. The Technical assessment for bonded screw anchors according to the EAD 332795 [1] is instrumental to a design method in line with EC2, part 4 [2], and regulated through the additional provisions given in a Technical Report issued by EOTA, the TR 075 [3]. This document coordinates the design method in its general aspects, however for the technical approach it endorses sections of the Eurocode 2, part 4.

The EOTA TR 075 [3] is needed because the construction product type “bonded screw fastener” is not explicitly mentioned in the Eurocode 2 – part 4 [2] and instructions on which design path to follow are required. In addition, some equations and criteria had to be adapted considering the outcome of the technical assessment for the new product type, as described in the EAD 332795 [1]. The equations of Eurocode 2, part 4 [2] regulating bonded fasteners consider a characteristic bond strength (τ_{Rk}) as an input for the calculations to be applied for the design at the specific anchorage configuration. Therefore, those had to be adapted to receive as an input for calculation directly a characteristic resistance force value ($N_{Rk,p}$) in case of bonded screw fasteners.

Additionally, the EOTA TR 075 [3] addresses the verifications to seismic loading and to fire exposure to explicitly regulate those design cases as well. In both cases the text from the Eurocode 2 part 4 is simply adapted to receive the correct parameter out of the technical assessment.

Note: Due to their novelty, bonded screw fasteners are handled differently in the design than a screw fastener, which in some cases may result in calculated resistance values of a concrete screw being higher than a bonded screw. This is since these two technologies are designed completely differently from a structural point of view and the bonded screw is assigned to a chemical anchor. Finally, to know the advantages of the bonded screw, this should be compared with chemical systems.

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In summary, there is no technical deviation between the design method of EOTA TR 075 [3] and the design method for bonded fasteners provided in Eurocode 2, part 4 [2]. With the main design provisions for anchors included in the Eurocode, the technical reports issued by EOTA allow more flexibility in the delivery of state-of-the-art criteria to the engineering community.

This complementary regulatory setup supporting the design practice is effective in ensuring both an adequate verification of the safety level for the fastening applications and the immediate transfer of new research findings. **Table 2** provides an overview about the main equations between the 3 fastening types.

Verification characteristic	Technical parameter	Bonded screw fasteners – TR 075	Bonded fasteners – EN 1992-4
Resistance to pullout and combined failure	Characteristic resistance	$N_{Rk,p} = N^0_{Rk,p} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np}$ $N^0_{Rk,p} = \Psi_{sus} \cdot N'_{Rk,p}$	$N_{Rk,p} = N^0_{Rk,p} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np}$ $N^0_{Rk,p} = \Psi_{sus} \cdot \tau_{Rk} \cdot \pi \cdot d \cdot h_{ef}$
	Group verification	$N^g_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$ (group effects)	$N^g_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$ (group effects)
Resistance to concrete cone failure	Effective embedment	γ_{Mc} [-] $0{,}85\,(h_{nom}-0{,}5h_t-h_s) \le h_{ef} \le h_{nom}$	γ_{Mc} [-] $h_{ef} = h_{nom}$
Seismic design - Resistance to pullout or combined failure	Characteristic resistance $R^0_{k,p}$ (eq. C.8, EN 1992-4)	$N_{Rk,p,eq}$ $= N^0_{Rk,p,eq} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np}$ $N^0_{Rk,p,eq} = \Psi_{sus} \cdot N'_{Rk,p,eq}$	$N_{Rk,p,eq}$ $= N^0_{Rk,p,eq} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np}$ $N^0_{Rk,p,eq} = \Psi_{sus} \cdot \tau_{Rk,eq} \cdot \pi \cdot d \cdot h_{ef}$
Fire design - Resistance to pullout or combined failure	Characteristic resistance	$N_{Rk,p,fi}$	$\tau_{Rk,fi}$

Table 2 Comparison of the design methods of bonded screw fasteners and bonded fasteners

A TECHNICAL NOTE

to the main concerns from the specifier community

05

Some designers have concerns that screw anchors might show risk of "self-loosening" and may "unscrew" themselves e.g. in case of vibration and it is clear that nobody wants to have a turning concrete screw under loading for the next 50 years or even 100 years, which may lead to other problems. Hilti developed the Hilti HUS4 screw and Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) where a complex set of design parameters involving the characteristics of the thread was arranged such that the resistance against unscrewing under the approved load parameters is optimized and of course verified by tests.

As there is no clear request concerning that topic in the EAD process Hilti developed a new test setup which is based on the philosophy of the Junker test and takes into account DIN 65151 which was adapted to conditions found in anchorages to concrete conditions. Hilti HUS4 screw and Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) were tested under a given displacement amplitude considering different test frequencies. The baseplate was installed on a concrete block and exposed to simulated vibrations at a 90° angle to the Hilti HUS4 screw and Hilti HUS4 bonded screw fastener. To measure any rotation of the system, the head/nut was market as shown in **Fig. 5**. Even after 15 min no signs of unscrewing was detected which ensures that Hilti HUS4 screw and Hilti HUS4 screw with HUS4-MAX capsule bonded screw fastener is optimized against unscrewing within the scope of the application due to a complex set of design parameters involving the characteristics of the thread.

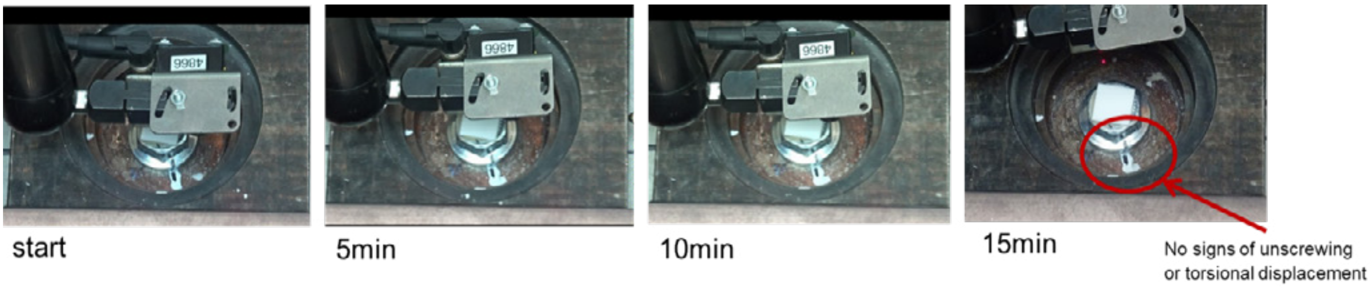

Fig. 5 No signs of unscrewing for Hilti HUS4 screw and Hilti HUS4 screw with HUS4-MAX capsule from start of the test to the end of the test

DESIGNER BENEFITS

of Hilti bonded screw fastener depending on the applications

06

The Hilti bonded screw fastener (Hilti HUS4 screw with HUS4-MAX capsule) carries an assessment according to EAD 332795 [1] and is therefore qualified for the usage in conjunction with EOTA TR 075 [3] / EC2, Part 4 [2] and may provide you as engineer design advantages due to the following reasons:

(a) Add structural safety since conditions influencing the bond behavior (e.g. temperature) are absorbed by the concrete screw. Take advantage of full removability and find design solutions even for the smallest edge and spacing distances.

(b) Even for installers, using the Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) means you no longer must deal with curing time, cleaning, torqueing, mandatory accessories, and restrictions of drilling technics.

We see these benefits especially for the following application:

1) Low to medium duty primary structures and its secondary members
in normal weight cracked and non-cracked concrete (C20/25 to C50/60) under static, quasi-static and seismic (C1) loading. The highlight is provided by the double holding function (undercut & adhesion).

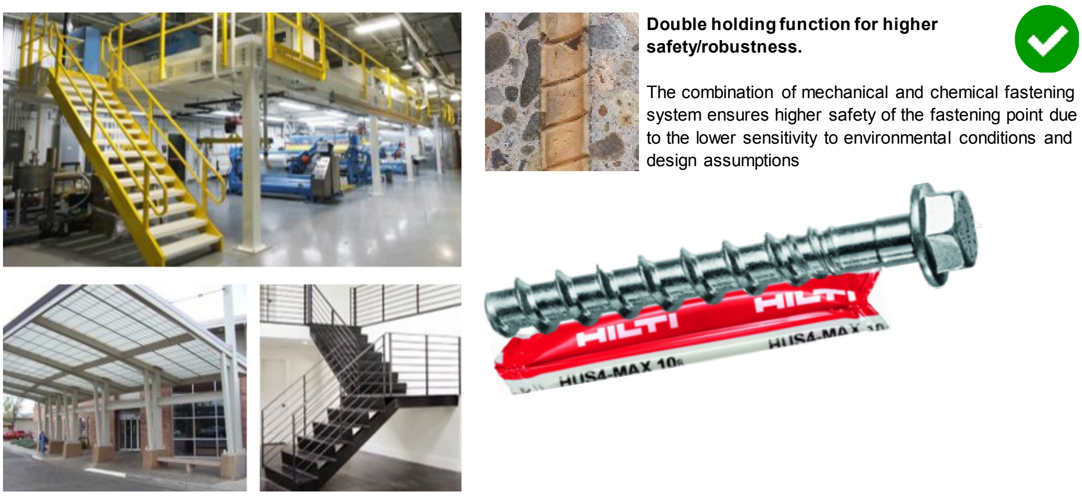

Fig. 6 Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) for low to medium duty primary structures, its secondary members, and the provided design advantages of having a total design flexibility and the benefit of the reduced sensitivity concerning environmental conditions and design assumptions as discussed before

DESIGNER BENEFITS

of Hilti bonded screw fastener depending on the applications

06

2) Medium duty, non-structural but safety relevant applications in normal weight cracked and non-cracked concrete (C20/25 to C50/60) under static, quasi-static and seismic (C1) loading. Even if the application is non-structural this does NOT mean there is NO safety relevance. The EOTA TR 075 [3] / EC2, part 4 [2] 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 like handrails, roofs, and lightweight steel structures. For such applications Hilti HUS4 screw and Hilti HUS4 bonded screw fastener provides you the possibility of designing with smallest edge and spacing distances as used with chemical anchors while also the Hilti HUS4 bonded screw fastener protects the borehole against standing water. In addition, even in conjunction with the mortar capsule, the Hilti HUS4 bonded screw fastener is still completely removable, **see Fig. 7**.

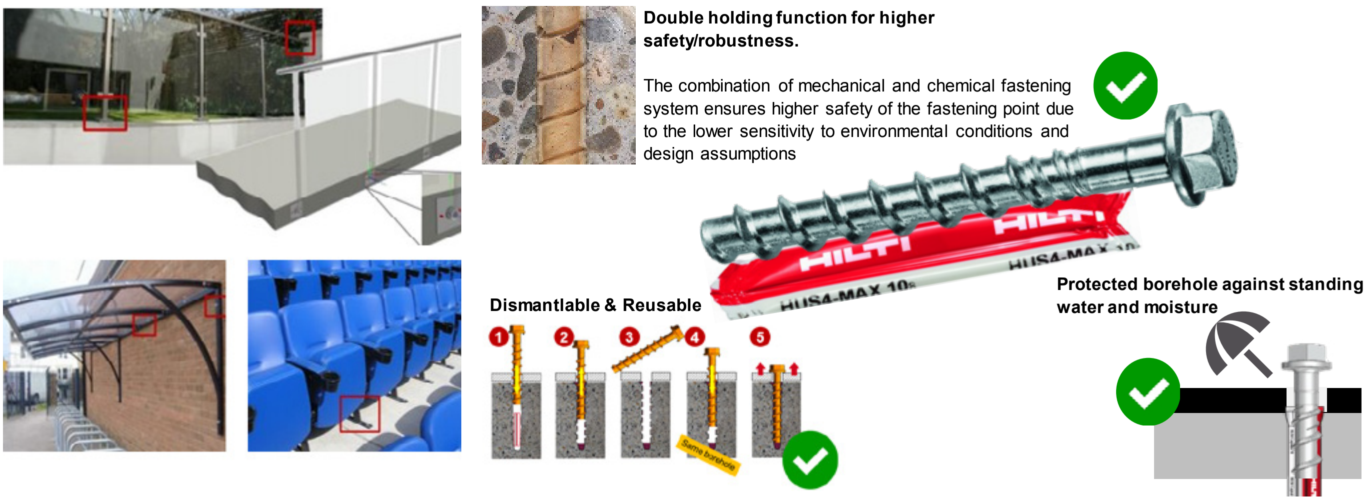

Fig. 7 Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) for non-structural but safety relevant applications and the provided design advantages of smallest edge and spacing distances, borehole protection from humidity and full removability

DESIGNER BENEFITS

of Hilti bonded screw fastener depending on the applications

3) Designing building equipment, building systems and machinery with Hilti HUS4 screw and HUS4-MAX capsule (bonded screw fastener) in normal weight cracked and non-cracked concrete (C20/25 to C50/60) under static, quasi-static and seismic (C1) loading. Poor performance of fastenings for equipment, and systems is the greatest contributor to damage and business interruption. The double holding function and removability when changing the position of the equipment provides you the advantages of being more flexible against functional changes. Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) and Hilti filling set, is a substance tight solution for coated floors.

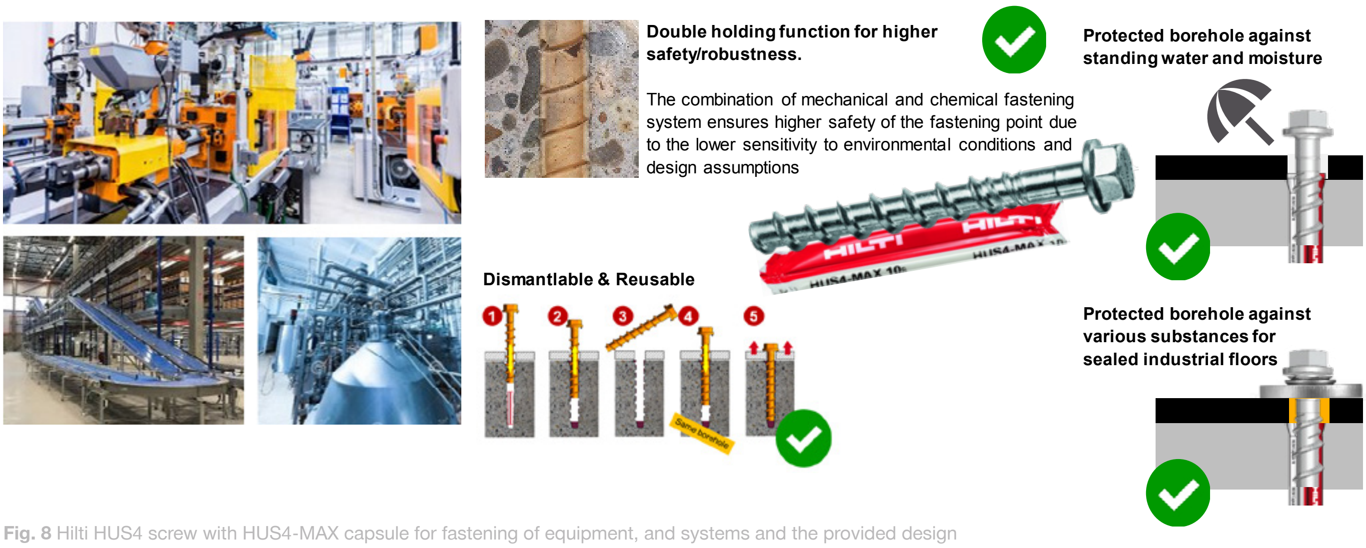

Fig. 8 Hilti HUS4 screw with HUS4-MAX capsule for fastening of equipment, and systems and the provided design advantages of smallest edge and spacing distances, borehole protection from humidity and various substances for sealed industrial floors and full removability

SUMMARY

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The new HUS4 is the fourth generation of a post-installed, self-locking concrete screw using mechanical interlock for a reliable load transfer mechanism in cracked and non-cracked concrete, fresh concrete, and other base materials with top edge productivity. The new Hilti HUS4 screw with HUS4-MAX capsule (bonded screw fastener) adds mortar to the concrete screw and reduce the sensitivity to design conditions and design assumptions by having the same productivity focus.

This is because conditions influencing the bond behavior, such as temperature, are absorbed by the concrete screw. Also, contractor benefit from your design as they do not have to deal with curing time, borehole cleaning, manual torqueing or other mandatory accessories or restrictions in drilling technics.

This system is assessed according to EAD 332795 "Bonded screw fasteners for use in concrete" [1] and can be designed in line with EC2, part 4 [2], and regulated through the additional provisions given in a Technical Report issued by EOTA, the EOTA TR 075 [3].

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

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