POSSIBILITIES AND LIMITATIONS OF ON-SITE ANCHOR TESTING

Don't guess. Test.
And interpret correctly.

Version 1.1
March 2023

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1. INTRODUCTION

If you have the following questions, you will find the answers in this document.

- "Why is on-site testing of anchors useful and under which conditions?"
- "We did proof loading on the jobsite with Hilti and with other products. The results are the same, so why should I use Hilti?"

2. ABSTRACT

On-site testing is one important element of the inspection of anchoring or post-installed rebar activities where:

- additional assurance of installation quality is deemed necessary (non-destructive proof-loading)

or where:

- resistance values for the design are missing for a similar but not identical base material, as given in the relevant approval document of a specific anchor type (destructive pull-out test or non-destructive proof-load test).

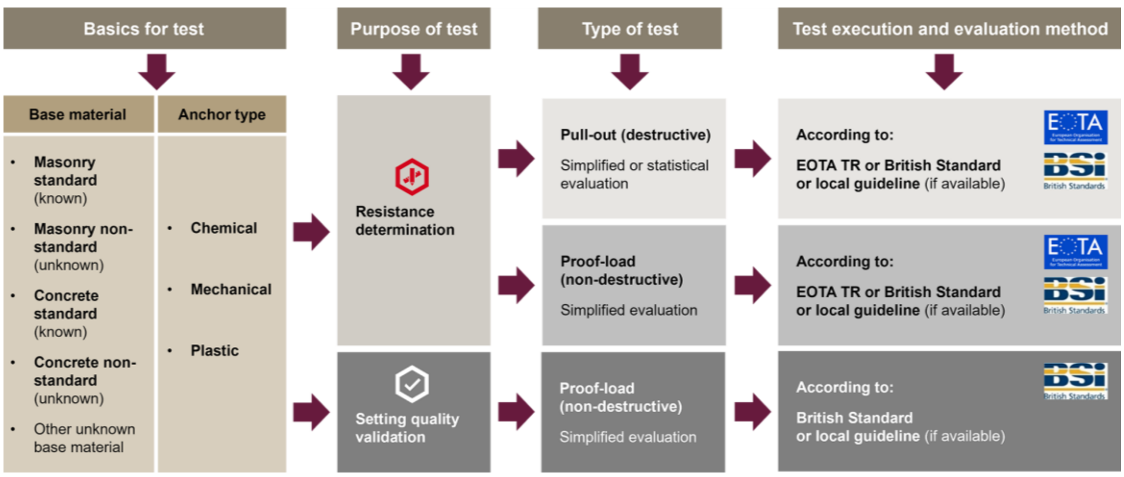


Fig.1 Hilti test execution and evaluation framework based on base material and anchor type, purpose and type of on-site test.

However, if the interpretation of on-site testing results is not done correctly, this assessment could compromise the stability of the structure, put human life at risk and/or lead to considerable economic consequences.

The statements above are explained and justified within this document.

3. GENERAL BACKGROUND

Hilti anchor and post-installed rebar systems carrying an approval, installed according to the manufacturer's installation instructions and in base materials within the scope of the approval do not require on-site testing for performance verification. Generally speaking, you will encounter just three situations when on-site testing should be performed:

1. To **determine the design resistance** in a similar but not identical material as given in the related approval (destructive or non-destructive tests)
2. To **validate the quality of installation** of anchors used on the job site (non-destructive tests)
3. Combination of (a) with additional geometrical requirements like edge distances, rebar/rod diameter etc. that are different to the values reported in the related approval

Non-destructive loading (proof loading) is done by applying tension loads. The selected load level is sufficiently high to provide assurance of correct installation or to determine targeted design resistance values, but not so high as to result in damage (e. g. in the form of yielding or permanent slip) to a correctly installed anchor. Proof loads should be maintained long enough to enable a determination of no anchor or rebar movement. Given this objective, it should be clear that proof loads are set as a percentage of the tested tension capacity of the anchor or rebar, not the design tension load.

Note that, depending on the embedment to diameter ratio and the steel grade, this load might or might not subject the anchor to yield level stresses. Where lower yield steels are used, it should be verified that the proof loads do not exceed 80% of the nominal yield stress of the steel anchor components.

If a proof load is used to verify proper installation, proof loading equipment may have load reactions close to the anchor but with sufficient clearance so any movement would be visible. If a proof load is used to determine design resistance values, proof loading equipment may have load reactions far away from the anchor to determine the base material strength. Note that Hilti provides a complete on-site testing service with the latest equipment, including a detailed test report and evaluation report.

Destructive loading is also done by applying tension loads. The load level is selected sufficiently high to result in damage (e.g., in the form of yielding or base material failure).

However, on-site testing with one or multiple products independent of the reason **can never:**

1. Serve as a substitution of the approval testing for assessing the suitability of an anchor
2. Serve as a means to conclude which is a "better" product by comparing loads from on-site testing of product A vs product B

Although no universal standard exists in Europe for conducting on-site testing, this type of assessment has been in use as an adjunct to anchor installation quality control and for the determination of design resistance for many decades. Therefore, Hilti investigated the existing national and European standards to provide a consistent and global on-site testing service that is state of the art.

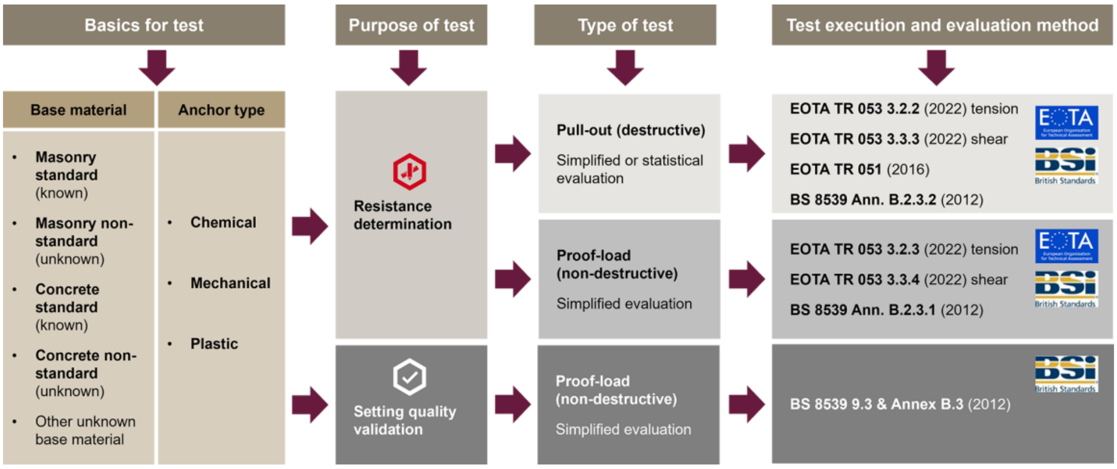


Fig.2 Hilti proposal for test execution and evaluation method based on base material and anchor type, purpose and type of on-site test.

As shown in Fig. 2, the relevant testing and evaluation methods are:

1. **EOTA TR 053 3.2.2, 3.2.3, 3.3.3 and 3.3.4 (2022).** Metal injection anchors for use in masonry, recommendations for tests to be carried out on construction works
2. **EOTA TR 051 (2016).** Plastic anchors for multiple use in concrete and masonry for non-structural applications, and plastic anchors for fixing of external thermal insulation composite systems with rendering, recommendations for tests to be carried out on construction works
3. **British Standard 8539 Annex Ann. B.2.3.1 and B.2.3.2 (2012).** Code of practice for the selection and installation of post-installed anchors in concrete and masonry, tests to determine the resistance and site-testing regimes
4. **British Standard 8539 9.3 and Annex B (2012).** Code of practice for the selection and installation of post-installed anchors in concrete and masonry, tests to check the quality of installation and site testing regimes

4. HOW MANY ANCHORS / POST-INSTALLED REBARS SHOULD BE TESTED?

There is no universal rule regarding the percentage of anchors or rebars that should be tested, nor is there any existing statistical basis for the percentages usually specified. Therefore, Hilti investigated the existing national and European standards to provide a proposal for the number of tests that should be done.

However, the numbers as given in Fig. 3 should be seen as an indication only. This is because the requirements for the proof load program may vary significantly from case to case.

Clearly, the number of anchors to be proof loaded is dictated by structural safety as well as practical considerations and the reasons for testing. For example, while it is typical on a large job to require that anywhere from 2.5 to 20 percent of the installed anchors of a given type and size be proof loaded, this requirement must be adjusted where, say, only four large anchors in a baseplate are to be verified. In such a case, it is not unreasonable to require that all four anchors be proof loaded, particularly if the consequences of failure are significant.

For highly redundant applications and less critical applications such as rebar doweling for shotcrete applications or slab on grade doweling, proof loading of a minimum random sampling of 5% of the anchors may suffice. Ultimately, the Engineer of Record should determine the sampling rates.

Hilti Engineers are available to advise you, but the decision remains with the Engineer of Record

Purpose	Type	Method	Number of test anchors	Anchor type	Base material
Resistance determination	**Tensile** tests to failure (pull-out; destructive)	**EOTA TR 053 3.2.2** (2022)	$n_{Test} \geq 15$ (simplified evaluation) $n_{Test} \geq 5$ (statistical evaluation)	• Chemical	• Masonry known • Masonry unknown
		EOTA TR 051 (2016)	$n_{Test} \geq 15$	• Plastic / Screws • ETICS • Mechanical [1)]	• Masonry known • Masonry unknown • Concrete unknown
		BS 8539 Ann. B.2.3.2 (2012)	$n_{Test} \geq 5$	• All types	• Masonry known • Masonry unknown • Concrete unknown
Resistance determination	**Tensile** tests to proof-load (non-destructive)	**EOTA TR 053 3.2.3** (2022)	$n_{Test} \geq 15$	• Chemical	• Masonry known • Masonry unknown
		BS 8539 Ann. B.2.3.1 (2012)	$n_{Test} = 5$	• All types	• Masonry known • Masonry unknown • Concrete unknown
Setting quality validation	**Tensile** tests to proof-load (non-destructive)	**BS 8539 9.3 + Ann. B.3** (2012)	$n_{Test} \geq 2.5\%$ OR $n_{Test} \geq 5\%$ Min. 3 fastenings	• All types	• All base materials
Resistance determination	**Shear** tests to failure (destructive)	**EOTA TR 053 3.3.3** (2022)	$n_{Test} \geq 15$ (simplified evaluation) $n_{Test} \geq 5$ (statistical evaluation)	• Chemical	• Masonry known • Masonry unknown
Resistance determination	**Shear** tests to proof-load (non-destructive)	**EOTA TR 053 3.3.4** (2022)	$n_{Test} \geq 15$	• Chemical	• Masonry known • Masonry unknown

[1)] Expanded / unofficial

Fig. 3 Number of tests to be performed according to evaluation method, purpose and reason (type).

5. LET'S GO ON-SITE AND DISCUSS A FEW SCENARIOS

5.1 Scenario A: Anchors with an approval, but set in unknown or uncertain base material. On-site testing to determine resistance

a1. Anchors approved for masonry installed in a non-standard masonry brick

a2. Anchor or a post-installed rebar approved for concrete to be installed in concrete where the concrete strength class is not known.

Is this the right scenario for Hilti on-site testing?
The answer is a clear "yes".

Why?
No technical data for the design of the anchor is available or the technical data for the specific fastening solution is incomplete. This is based on the fact that – as mentioned above – the base material is not sufficiently well known and not covered adequately by an approval, although it is within the category (similarity) and therefore comparable with the base material of the approval.

Why is the "similarity" of the base material so important?
We already know the influencing parameter on the concrete cone failure load of anchors anchored in normal weight concrete or masonry. The main parameters for concrete cone failure are embedment depth (h_{ef}) and concrete compressive strength (f_c). However, we have no indication how an anchor performs in a base material like ice or butter. Even if the on-site testing would give us "results" we are still not able to design, because we do not know the decisive parameters on the failure load. Consequently, the base material should be similar to the one in the scope of the approval.

Necessary information or questions which should be stated for Scenario A:

- Is the structure sensitive to possible damage or are there other architectural appearance issues?
- If the answer is **"no",** damage from testing can be accepted and destructive on-site tests may be conducted to determine the resistance of the fastening solution.
- It is important to note that in such a case a simplified or statistical evaluation can be performed. In this case we may need fewer tests.
- If the answer is **"yes",** damage from testing cannot be accepted. You need to rely on non-destructive on-site tests to determine the resistance of the fastening solution. A higher number of tests is required when only a simplified evaluation is possible.

Jobsite experience:
The mechanical properties of a base material, especially masonry, are not always what you would expect. Some weaker-looking bricks will deliver the tension values you expect, while others that you'd expect to manage higher tension loads fall short.

In one specific case, Hilti assisted a team on-site who estimated that the capacity of an anchor installed in a brick wall would be at least the minimum of our allowable load. He estimated right, but the design still had to be changed.

The injectable adhesive bonded effectively with the brick – no remarks there. As we performed on-site testing with the allowable load as an unconfined test (wide support), the brick was pulled right out of the masonry wall. The masonry mortar, which was like fine-grained powder, was to blame. So, the engineer chose to re-assess his design thanks to this sobering demonstration.

5.2 Scenario B: Anchors with an approval, set in known and approved base material. Proof loading as basis to check installation quality

b1. Approved anchor or rebar system is to be installed in known and approved base material. The designer included proof load requirements on the general notes sheet of the structural drawing set.

Is this the right scenario for Hilti on-site testing?
The answer is a clear "yes".

Why?
A scenario where on-site testing is included (proof load) in their structural drawing serves as one element in the big picture of quality assurance. Injection adhesive systems (such as epoxy mortar) have special requirements to ensure that the adhesive is correctly mixed and dispensed. These usually include dispensing a small quantity of adhesive from the mixing nozzle prior to injecting it into the hole. The objective of adhesive injection is to avoid entrained air. For long holes and holes drilled horizontally or overhead, special equipment such as extension tubes, stoppers and end caps may be specified to achieve a void-free injection. Therefore, proper installation techniques are needed for concrete anchors to perform as expected.

This, in general, can also be achieved if:

1. The personnel performing anchor installation are experienced and qualified to use the specific adhesive or anchor system being employed (such training can be requested from Hilti). For example, in the US post-installed adhesives must be performed by certified installers, while in Germany this certification is limited to post-installed rebar connections.
2. The initial installation is observed continuously, followed by periodic inspections as the installation continues. This is rarely done in Europe.

Therefore, non-destructive on-site testing (proof loading) may be performed to validate the installation quality of the installed fasteners according to Fig.1 and Fig. 2.

Necessary information or questions which should be stated:
What are the consequences for the case where an anchor fails the proof-load test?

These consequences should be specified upfront by the responsible engineer to keep the construction project going.

5.3 Scenario C: Limitations of on-site testing with regards to comparing different, individual products

First of all, this is the wrong scenario for on-site testing even if it happens quite often.

c1. Anchor or post-installed rebar performance of different products are compared on the jobsite via on-site testing by means of comparing the measured load values of the individual products.

Is that the right scenario for Hilti on-site testing?
The answer is a clear "no". Taking the wrong conclusions from on-site testing could compromise the stability of the structure, putting human life at risk and/or lead to considerable economic consequences.

Why?
Now we have to dig a little bit deeper.

Fundamentally, all types of safety-relevant anchors should be designed in such a way that they are resistant and durable under service loads – and also provide an adequate margin of safety against failure. Therefore, in the European Union, United States and other countries, approval processes exist to provide an independent assessment. Approvals are based on tests intended to verify the **suitability of a system** and to determine the **admissible service conditions.**

Suitability tests are designed to verify the effectiveness of the anchor under unfavorable application conditions. These tests are generally conducted in concrete with a strength at the lower and upper end of the usual field of application. Tests in cracked and uncracked concrete specimens may be chosen, depending on the intended use of the anchor. The effects of installation variances are checked insofar as they are relevant. Factors investigated and covered in the approval documents may include:

- Drill bit tolerance extreme values
- Varying technique and effort applied to cleaning the borehole
- Variations in the degree of anchor expansion
- Proximity of the anchor to reinforcing bars
- Variations in the moisture content and temperature in the concrete
- Aggressive/reactive substances

These tests may account for the influence of sustained and repetitive loads acting on the anchorage itself as well as the component in which the anchor is placed.

Suitability tests also consider circumstances which may occur while installing the anchor and during service life. In summary, we can say a product sensitive to these circumstances may have comparable test loads during on-site testing compared to a non-sensitive product. However, if all circumstances were tested (involving hundreds of tests, as carried out during the approval process) the differences could be significant or it could even mean that such a product would never get an approval.

Another buzzword for scenario C is “long term behavior”, and we should remember that the estimated working lifetime of an anchor or rebar is at least 50 years.

The long-term behavior of anchors or post-installed rebars is also checked within the approval process with the most relevant tests named below:

- Functioning under sustained loading (creep test)
- Crack movement test (mechanical and bonded anchors)
- Functioning under freeze/thaw conditions (bonded anchors only)
- Tests for checking durability (bonded anchors only)

This behavior can also **never be checked** by a “simple on-site test” and value comparison.

Therefore, the wrong conclusion of Scenario C may lead to reaching a critical displacement value of the anchor or post-installed rebar during the working life by means of pullout failure.

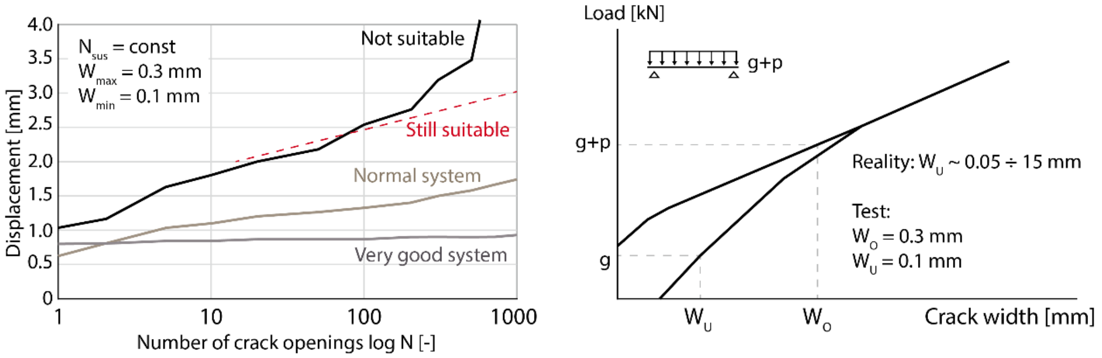
Let’s have a deeper look into the crack movement test mentioned above. It may seem surprising, but this test is the decisive one for most anchoring products. Products showing highest load values in a pullout test may fail in the crack movement test.

Without going into detail on the exact procedure, the tests according to EAD 330232-00-0601 are conducted as follows:

After installing the anchors in cracked concrete, the anchors are under **sustained load** based on the characteristic load evaluated in a short-term test/pullout test. While the anchors are loaded under tension, cracks are opened between 0.1 mm and 0.3 mm 1,000 times and the displacement of the anchor under tension is measured. During these tests the measured displacement should be below the constant value of 3 mm.

Fig. 4a shows the results of three different products by means of plotting the measured displacement as a function of the numbers of crack openings. While two systems would fulfill the requirements concerning the maximum displacement, the other would not fulfill the requirements due to the fact that measured displacement is larger than the limiting displacement of 3 mm resulting in pullout failure during its lifetime.

The next question would be: **“Why do we do such tests?”**



a) Measured displacement as a function of crack openings for crack opening test

b) Load acting on a beam as a function of the crack width

Fig.4 Test results of crack movement test (a) and reasonable explanation for the crack movement test (b)

As a structure responds to permanent load, it experiences displacement and consequently deformation. This deformation leads to the formation of cracks.

This behavior is schematically given in Fig. 4b. In Fig. 4b the permanent load “g” and variable load “p” are given as a function of the crack width for a beam. During the life of the beam no cracks will probably occur if the permanent load is acting on the beam the first time. However, if the variable load is considered in combination with the permanent load (g+p), the deformation will increase and will lead to opening of cracks in the beam. If the beam is unloaded to the level of the permanent load, the deformation will again decrease by means of reducing the crack width. However due to the rough surface of the cracked surface, the crack will not be fully closed (i. e. closed to zero). Therefore, the lower crack width is around 0.1 mm. During the lifetime of the beam this crack opening will be repeated. EAD 330232-00-0601 assesses 1,000 openings and closings for representing the lifetime of the adhesive/bonded anchor.

This behavior of the anchors can never be checked by on-site testing. However, this is included in the basic characteristic bond strength values provided in the relevant approval document.

In the words of an experienced engineer:

“Testing is easy if you know what you're doing. It doesn't have to take a lot of time if you use Hilti’s on-site testing service. And it can give you peace of mind knowing you are not guessing. How do you know when you're guessing? You maybe think about your design when you get home. You dream about a certain connection. Something's not quite right but you're not sure exactly what it is”.

“DON’T GUESS. TEST. INTERPRET CORRECTLY AND GET PEACE OF MIND!”

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