The possibilities and limitations of on-site testing of anchors

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ABSTRACT

On-site testing is one important element of the inspection of anchoring/rebar activities where additional assurance of installation quality is deemed necessary (non-destructive proof loading) or where resistance values for the design are missing due to 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). However, if the interpretation of on-site testing results is not done correctly, this assessment could compromise the stability of the structure, cause risk to human life and/or lead to considerable economic consequences.

KEYWORDS: anchors, on-site testing, quality, resistance

1. General Background

Hilti anchor and rebar systems carrying an approval, installed according to the manufacturers installation instruction and in base materials within the scope of the approval do not require on-site testing for performance verification. There are in general only three reasons why on-site testing should be performed

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

Non-destructive loading (proof loading) is done by applying tension loads. The load level is selected 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 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 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 engineering service including the latest equipment, the on-site evaluation, and a detailed 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**

(a) Serve as a substitution of the approval testing for assessing the suitability of an anchor
(b) 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.

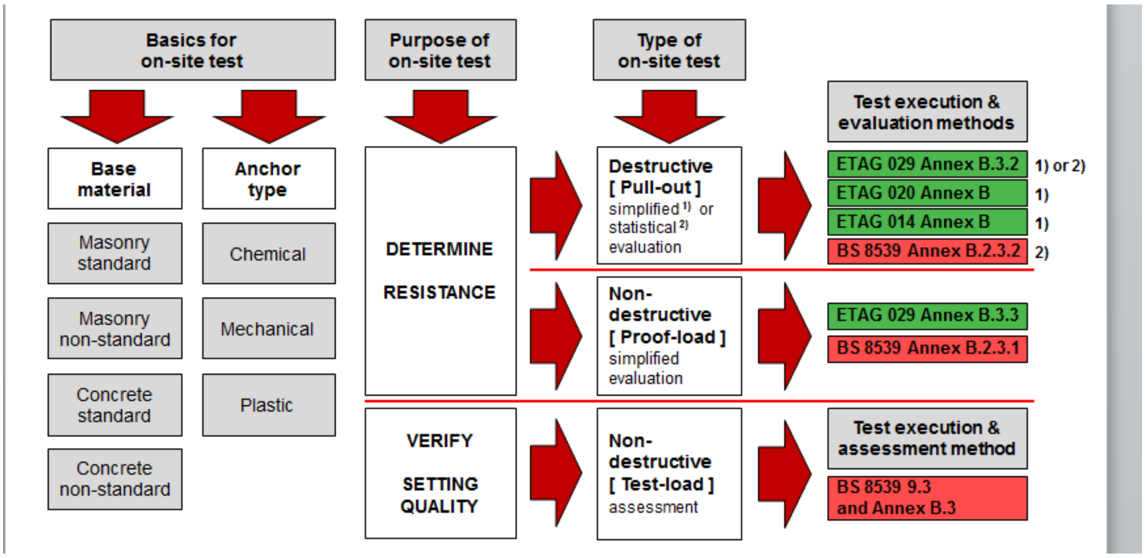


Fig.1 Hilti proposal for test execution and evaluation method based on type of onsite test, purpose, base material and anchor type

As shown in Fig. 1, the relevant testing and evaluation methods are:

(a) ETAG 029 Annex B.3.2, Metal injection anchors for use in masonry, recommendations for tests to be carried out on construction works
(b) ETAG 020 Annex B, Plastic anchors for multiple use in concrete and masonry for non-structural applications, recommendations for tests to be carried out on construction works
(c) ETAG 014 Annex B, Plastic anchors for fixing of external thermal insulation composite systems with rendering
(d) British standard 8539 Annex B.2.3.2 Code of practice for the selection and installation of post-installed anchors in concrete and masonry

While (a) provides a **simplified evaluation** requiring an increased number of test samples and a **statistical evaluation** allowing less tests. (b) and (c) provide a simplified evaluation only while (d) provides a statistical evaluation only.

2. How many anchors/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 again 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. 2 should be seen as an indication only as the requirements for the proof load program may vary significantly from case to case.

Clearly, the number of anchors to be proof loaded for example is dictated by structural safety as well as practical considerations and reason for testing. For example, while it is typical on a large job to require that anywhere from 10 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. At the end the engineer on record should determine the sampling rates.

Testing methods - overview

	Method	Number of test anchors	Evaluation	Purpose	Type
1	ETAG 029 Annex B.3.2	$n_{Test} \geq 15$	Simplified analysis	Determine resistance	Destructive (pull-out tests)
		n_{Test} = 5 to 14	Statistical analysis		
2	ETAG 020 Annex B	$n_{Test} \geq 15$	Simplified analysis		
3	ETAG 014 Annex B	$n_{Test} \geq 15$			
4	British Standard 8539 Annex B.2.3.2	n_{Test} = 5 to 15 (or more)	Statistical analysis		
5	ETAG 029 Annex B.3.3	$n_{Test} \geq 15$	Simplified analysis	Determine resistance	Non-destructive (proof-load / test-load)
6	British Standard 8539 Annex B.2.3.1	n_{Test} = 5			
7	British Standard 8539 9.3 + Ann. B.3	$n_{Test} \geq 2.5\%$ OR $n_{Test} \geq 5\%$ Minimum 3 fastenings	Assessment	Validate quality	

Fig. 2 Number of test to be performed according to evaluation method, purpose and reason (type)

3. Let´s go virtually on-site and discuss a few scenarios

3.1. Scenario A. Anchors approved for masonry installed in a non-standard masonry brick/ anchors or post-installed rebar approved for concrete to be installed in concrete where the concrete strength class is not known.

Is that the right scenario for 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 but it's 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 know very well 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 is performing in a base material like "ice" or a "peace of 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"**, damages created by testing can be accepted and in such a case destructive on-site tests may be conducted to determine the resistance of the fastening solution.

Good to know, in such a case a simplified or a statistically evaluation can be performed…remember in that case we may need less tests.

If the answer is "**yes"**, damages created by testing cannot be accepted then non-destructive on-site tests may be conducted to determine the resistance of the fastening solution. It is also good to know that when only a simplified evaluation is possible, a higher number of tests are required.

3.2. Scenario B. Approved anchor or rebar system are installed in known and approved base material. The designer included proof load requeriments on the general notes sheet of the structural drawing set.

Is that 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 piece of the big picture of quality assurance. Injection adhesive systems in particular have special requirements to ensure that the adhesive injected is correctly metered and mixed. These usually include, for each new cartridge, dispensing a quantity of adhesive from the mixing nozzle prior to beginning injection of adhesive in the hole. The objective of adhesive injection is to avoid entrained air. For long holes and holes drilled horizontally or overhead, the MPII may specify special equipment such as extension tubes, stoppers and end caps to achieve a void-free injection. Therefore in general proper installation techniques are needed for concrete anchors to perform as expected.

This in general can also be achieved if

(a) The personnel performing anchor installation are experienced and qualified to use the specific adhesive or anchor system being employed (note that Hilti offers exactly such kind of trainings). Therefore the US requires that all post-installed adhesives must be performed by certified installers while in Germany this certification is limited to post-installed rebar connections

(b) The initial installation is observed continuously proceeded thereafter by periodic inspections as the installation continues. This is rarely done in Europe

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

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 moving.

3.3. Scenario C. First of all, this is the wrong scenario for on-site testing even if it happens quite often. Anchors 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 significantly compromise the stability of the structure, cause risk to human life and/or lead to considerable economic consequences.

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

Fundamentally, all type of safety relevant anchors should be designed in such a way, that they are resistant and durable under service loads and 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 proper function of the anchor under unfavorable application conditions. These tests are generally conducted in concrete with a strength lower and upper end of the usual field of application and may include tests in cracked and non-cracked concrete specimens 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 tolerances extremes, varying technique and effort applied to cleaning the borehole, variations in the degree of anchor expansion, proximity of the anchor to reinforcing bars, and variations in the moisture content and temperature in the concrete and 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 test also take account of 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 BUT if all circumstances would be tested (what is done in the approval process and we are talking about hundreds of tests) the differences could be significant or it could even happen that such a product would never get an approval.

Another buzzword for scenario C is "long term behavior" and we should remember that the expected life-time 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 <u>never be checked</u> 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. Whether you believe me or not this test is for most anchoring products the decisive one. Products showing highest load values in a pullout test may fail in the crack movement test.

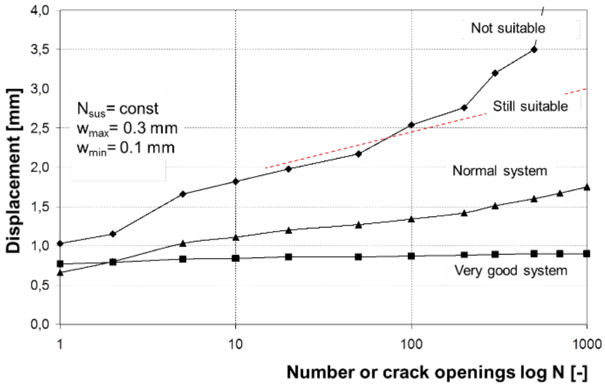
Without getting in detail of the test procedure, the tests are conducted as follows:

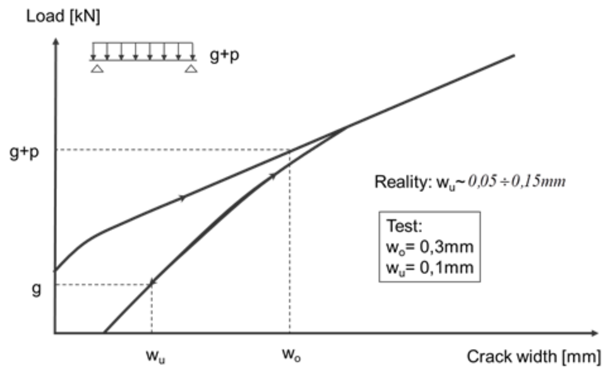
After installing the anchors in cracked concrete the anchors are under **sustained load** based on the characteristic load evaluated in short term test/pullout test. While the anchors are loaded under tension, cracks are opened between 0.1mm and 0.3mm 1000 times and the displacement of the anchor under tension is measured. During these tests the measured displacement should be below the constant value of 3mm.

Fig. 3a 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 3mm resulting in pullout failure during its life-time.

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

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





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

This behavior is schematically given in Fig. 3b. In Fig. 3b the permanent load "g" and variable load "p" are given as a function of the crack width for a beam. In the life of the beam probably no cracks will occur if the permanent load is acting on the beam the first time. However if the variable load will be taken into account 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 will be unloaded to the level of the permanent load again the deformation will decrease be means of reducing the crack width. However due to the rough surface of the cracked surface the crack will not be fully, i.e. closed to zero. Therefore the lower crack width is around 0.1mm. During the lifetime of the beam this crack opening will be repeated. ETAG assess 1'000 openings and closings for representing the life-time 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.

"Don't guess. Test. But interpret it correctly. And get peace of mind!"