Welcome
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Creep Behavior of Adhesive Anchoring Systems
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Summary and Action
Boston - Big Dig Tunnel Failure
Situation

Key message of the synopsis of NTSB report HAR-07-02 regarding the fatal accident in the Big Dig tunnel:

“Insufficient understanding among designers and builders of the nature of adhesive anchoring systems”
Situation

• The NTSB report concluded that poor creep resistance of the adhesive anchor was the primary contributor to the anchor failure.

• The report also states that the anchors were not installed correctly and that this influenced their capacity significantly.

• The Adhesive Anchoring System that failed in the Big Dig tunnel was not a Hilti product.
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Summary and Action
What is creep?

“What flows…” (Heraclitus ~500 BC)
What is creep?

Creep is the slow and continuous deformation of a material under a sustained stress and is mainly influenced by:

- material / product
- load level & duration of loading
- temperature
- installation

Creep can occur in various construction materials such as steel and concrete and is considered e.g. in reinforced concrete design.
Key pillars of Creep behavior

- Load (AC58) / design resistance (AC308)
- Installation temperature and in-service temperature
- Hole condition, hole cleaning, adhesive injection

Properly installed adhesive anchors in properly designed applications are extremely reliable
What is creep?

Creep behavior of Adhesive Anchoring Systems:

• Adhesive anchors exposed to sustained tension loads must have sufficient creep resistance for long term loading

• Rule of thumb: A higher temperature, a higher sustained load or a longer duration of loading \(\rightarrow\) increased creep displacement

• The creep displacement rate significantly decreases over time for a properly selected, designed and installed anchor \(\rightarrow\) viscoelastic behavior

Creep of Adhesive Anchoring Systems under sustained tension loads can be described as viscoelastic behavior
What is creep?

Creep basics:

The creep displacement rate significantly decreases over time → the displacement stabilizes

Load $N$ is maintained

Creep displacement: $s_{\text{creep}}$

time dependent

Load $N$ is applied

Initial elastic displacement: $s_0$

Total: $s(t) = s_0 + s_{\text{creep}}(t)$

Load $N = 0$

Time $t$
What is creep?

Hilti’s Expertise: Some creep tests with an Adhesive Anchoring Systems have been already running or the last 27 years and continue
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Summary and Action
How was the creep behavior tested?

A standard method to test and evaluate the creep behavior of Adhesive Anchoring Systems can be found in ICC-ES AC58

• AC58 was introduced in January 1995

• More than 25 different products from various manufacturers have been tested and evaluated

• The NTSB expressed no concern or criticism in AC58 qualifying suitable creep-resistant adhesives, instead stating that failing AC58 testing indicated an adhesive's inappropriateness for sustained-loading applications

• The creep test was optional

The test method under AC58 is appropriate for identifying the general suitability of Adhesive Anchoring Systems for sustained tension loads
How was the creep behavior tested?

AC58 Creep Test

Determine sustained tension load:
=> Ultimate load at 70F → \( \text{Nu} \times 0.4 \)

Determine displacement criteria:
=> \( s_u \) at ultimate load at 110F

Apply load / measure displacement:
For 42 days at 110F

Extrapolate displacement (600 days):
=> \( s_{\text{total}} = c \cdot \ln t + b \)

Conditions of acceptance \( s_{\text{total}} < s_u \)

A product could get an AC58 ICC-ESR without passing a creep test (optional!). The product was consequently limited to short term load.

Product not permitted for sustained loads

not passed
- Safety factor 5.33 (UBC)
- 6.67 (IBC)

passed:
- Safety factor 4
- Allowable load = \( \text{Nu} / 4 \)

Product permitted for sustained loads

ESR-TextExample:
“The allowable load values for the Adhesive installed with threaded rod or fully threaded bolts is permitted for short-term loads, such as those resulting from wind or earthquake forces only.”
How was the creep behavior tested?

If a creep test report (Series 17) was passed / submitted can be found in an ICC-ES ER / ESR in accordance with AC58:

3.0 EVIDENCE SUBMITTED

Data in accordance with the ICBO ES Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements (AC58), dated November 2001, including test reports for the following optional tests: axial tension testing of single anchors, establishing minimum edge distance, \( c = c_{\text{min}} \) (AC58 Test Series 5); axial tension testing of a group of two anchors, establishing minimum spacing distance, \( s = s_{\text{min}} \) (AC58 Test Series 9); shear testing of single anchors, establishing critical edge distance, \( c = c_{\text{cr}} \) (AC58 Test Series 13); shear testing of single anchors, establishing minimum edge distance, \( c = c_{\text{min}} \) (AC58 Test Series 14); creep testing (AC58 Test Series 17); dampness testing (AC58 Test Series 19); freezing and thawing testing (AC58 Test Series 20); and seismic shear and tension testing of threaded rods and rebar (AC58 Test Series 21).
How was the creep behavior tested?

Other locations in an ER / ESR where information can be found:

• Footnotes in load tables stating Factors of Safety (FS):
  FS = 4 → creep test passed,
  FS = 5.33 (UBC) or
  FS = 6.67 (IBC) → creep test not submitted

• Other locations:
  • “Findings” (ER - Section 4)
  • “Design” (ER - Section 2)
  • “Conditions of Use” (ESR – Section 5)
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Summary and Action
Effects of temperature on Adhesive Anchoring Systems

Temperature influences have to be considered throughout the lifecycle of an Adhesive Anchoring System:

- **Storage**
  - Observe Manufacturers recommended storage temperature

- **Installation**
  - Dispensing forces
  - Working times
  - Cure time
  - Load values

- **Lifetime (in-service)**
  - Base material
  - Adhesive & base material

**Temperature must be considered for Adhesive Anchoring Systems for the various stages of the fastening’s lifecycle**
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Summary and Action
Performance of adhesive anchors are related to installation procedures and accessories

Blowing out
- Blow-out pump
- Compressed-air gun
- Compressed-air gun + air nozzle

Brushing
- Bristle Brush
- Steel Brush

Injecting
- Injection nozzle
- Injection extension
- Piston plugs
PROFI Kits Help Ensure Proper Installation

- Installation Rebar Protocol
- Injection and blowing elongations
- Air gun
- Box for small elements
- HIT Profi case
- Piston plugs
- HIT Setting Instructions
- Steel Brushes and extensions
- MD 2500
- Safety goggles
- Air nozzles
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Summary and Action
How do Hilti products perform in creep tests?

Hilti’s current product portfolio passed an AC58 creep test:

- HIT-HY 150
  (A, ER-5193)
- HIT-HY 150 MAX
  (A, ESR-1967)
- HVU
  (A, ER-5369)
- HIT-HY 10
  (A, internal)
- HFX
  (A, internal)
- HIT-ICE
  (A, internal)
- HIT-RE 500
  (EP, ESR-1682)
- HIT-HY 20
  (A, internal)

(A=Acrylate, EP=Epoxy)
How do Hilti products perform in creep tests?

Fast Cure vs. Slow Cure:

There are two different basic resin types / reaction mechanisms that are currently used for chemical anchoring systems:

- Polymerization $\rightarrow$ Acrylate: shorter curing time (Fast Cure)
- Polyaddition $\rightarrow$ Epoxy: longer curing time (Slow Cure)
- There are some Epoxy based products that are chemically accelerated in order to achieve faster curing (Fast Cure Epoxies)
- Creep performance cannot be generalized for a basic resin type

Creep performance can only be determined by testing and evaluation in accordance with the available state of the art (AC58, AC308)
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Summary and Action
**What changes with AC308 - what are the reasons?**

AC58 evolved into AC308. The main developments:

<table>
<thead>
<tr>
<th>AC58</th>
<th>AC308</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extrapolation to 600 days only</td>
<td>Extrapolation to 10 years (elevated temp.)</td>
<td>better coverage of relevant time periods</td>
</tr>
<tr>
<td></td>
<td>50 years (normal ambient temp)</td>
<td></td>
</tr>
<tr>
<td>Test temperature fixed (110F)</td>
<td>Test temperature determined through</td>
<td>Wider temperature ranges possible</td>
</tr>
<tr>
<td></td>
<td>published service temperature range</td>
<td></td>
</tr>
<tr>
<td>Pass / Fail</td>
<td>Product can pass with reduced published</td>
<td>Application oriented evaluation</td>
</tr>
<tr>
<td></td>
<td>load and or published temperature range</td>
<td></td>
</tr>
<tr>
<td>Creep test optional</td>
<td>Creep test mandatory</td>
<td>No “backdoor” or misunderstanding</td>
</tr>
</tbody>
</table>

AC308 creep test is mandatory and published technical data directly depend on the result of creep tests.
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<tr>
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</tr>
</thead>
<tbody>
<tr>
<td>No Anchor Categories</td>
<td>Established Anchor Categories</td>
<td>Categories are related to system’s sensitivity to hole preparation and gives engineers transparency to system reliability.</td>
</tr>
<tr>
<td>Only evaluates one size (1/2”) and one embedment (4-1/2”)</td>
<td>Test full range of embedments to determine a system’s sensitivity to cleaning</td>
<td>A system’s sensitivity to hole cleaning is adequately evaluated</td>
</tr>
<tr>
<td>Requires continuous inspection for all adhesive anchors</td>
<td>Allows for periodic inspection</td>
<td>Systems proven to be reliable save time and money for the project.</td>
</tr>
<tr>
<td>No inspection procedure required</td>
<td>Manufacturer’s must submit inspection procedures for adhesive anchors</td>
<td>Guidance on proper inspection of anchors</td>
</tr>
</tbody>
</table>

www.hilti.com Creep behavior / September 2007 / TSDgp
Hilti HIT-RE 500-SD

- Strength design solution for adhesive products!
- Threaded rod, internally threaded inserts and rebar applications
- All seismic design categories under the 2003 and 2006 International Building Code® (IBC).
- Holes as deep as 20 times the rod or bar diameter.
- ICC-ES ESR-2322 report in accordance with AC308
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Summary and Action
Summary

• An adhesive anchorage that is properly qualified, designed and installed is appropriate for resisting sustained long-term loading

• AC58 is appropriate for identifying the general creep-resistance of Adhesive Anchoring Systems

• Hilti’s current adhesive products (HIT-RE 500, HVU [foil capsule], HIT-HY150 MAX, HIT-ICE, HIT-HY20, HIT-HY10, HFX, HIT-HY150), and these past adhesive products (HIT-C100, HVA [glass capsule], HSE2421, HIT-C20, HIT-C10) pass creep testing

• AC58 evolved into AC308 for adhesive anchors used in concrete – a stricter standard
Summary

• AC308 requirements further identify the creep-resistance properties of Adhesive Anchoring Systems for more specific temperature conditions / applications

• AC308 was developed prior to the Big Dig accident - it was not a response to that event

• The creep test requirements of AC308 have been harmonized with the latest state of the art to reflect the changed design environment associated with IBC 2006

• Hilti HIT-RE 500-SD has already successfully been tested under AC308 creep and other test requirements

• Hilti continues to implement AC308 testing for other products
What is “or equal”?

- There is no such thing as “or equal” based on just loads.
- Products have or have not been qualified for sustained tensile loads
- Products have limitations in regards to in service and installation temperature
- Products have limitations in regards to base material, drilling method, and hole condition.
- Only properly installed anchors achieve their optimum performance. Clarity and consistency of installation instructions and availability of these for installers on job sites are very important.

Suggested specifications:
We recommend the following “or equal” clause:
“Use Hilti [adhesive anchor system] or equal considering load resistance, in-service and installation temperature, availability of comprehensive installation instructions, and creep testing evaluation in accordance with the available state of the art (AC58, AC308) and design method".
We passionately create enthusiastic customers and build a better future