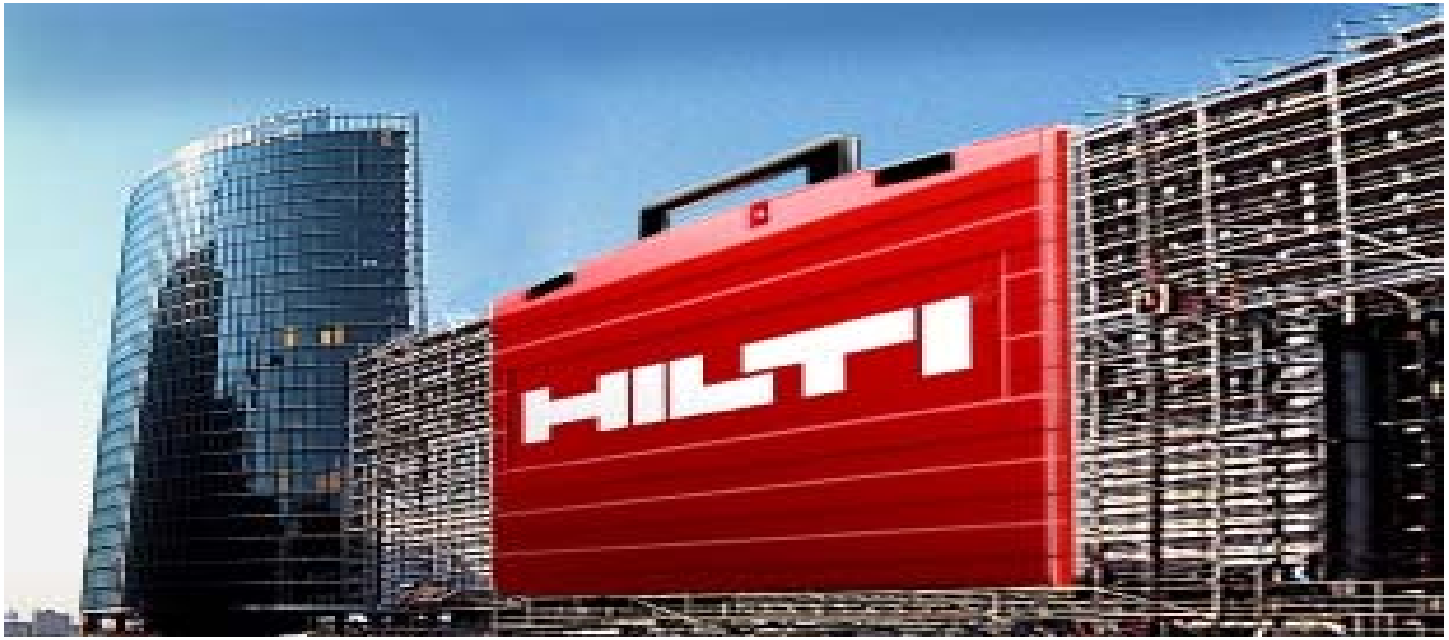


Welcome

Ellada Kosinska – Hilti Field Engineer

Lizanne Pepin – Hilti Field Engineer

Creep Behavior of Adhesive Anchoring Systems

Content

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 <u>not</u> a Hilti product**

Content

What is creep?

“Everything 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

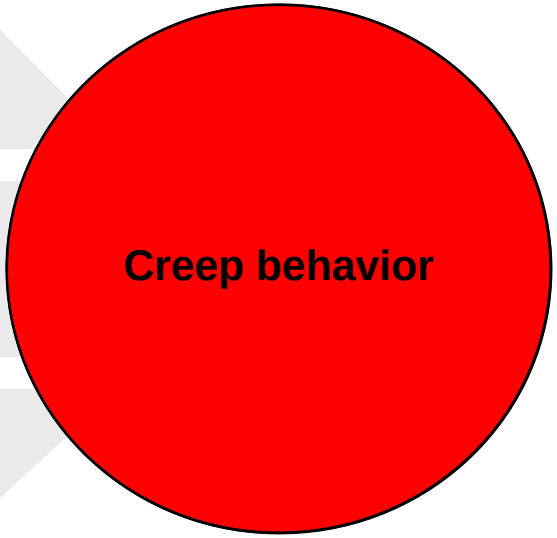
Creep is a typical behavior of construction materials that needs to be considered for design

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 → increased creep displacement
- The creep displacement rate significantly decreases over time for a properly selected, designed and installed anchor → viscoelastic behavior

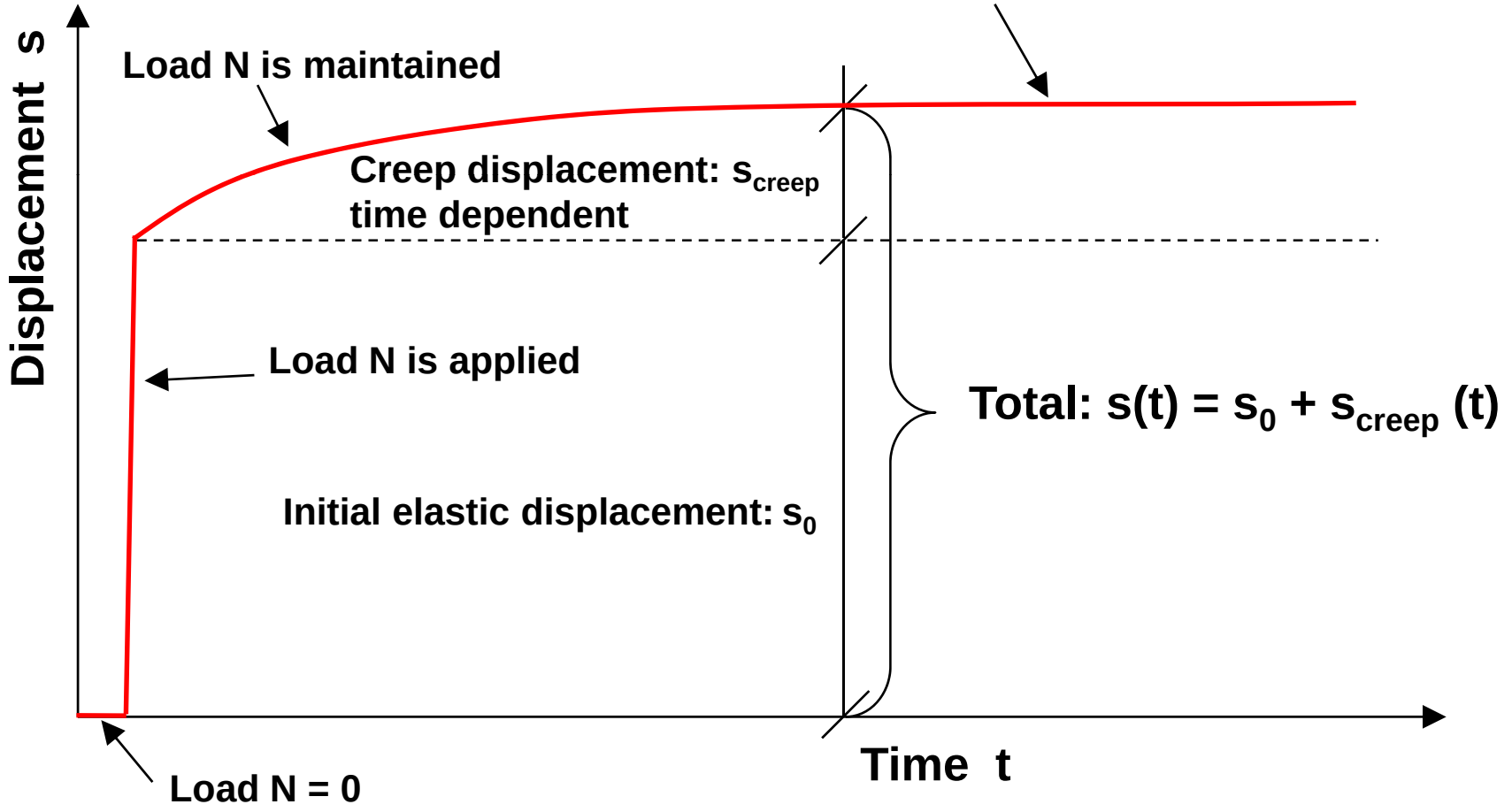
learn more

Creep of Adhesive Anchoring Systems under sustained tension loads can be described as viscoelastic behavior

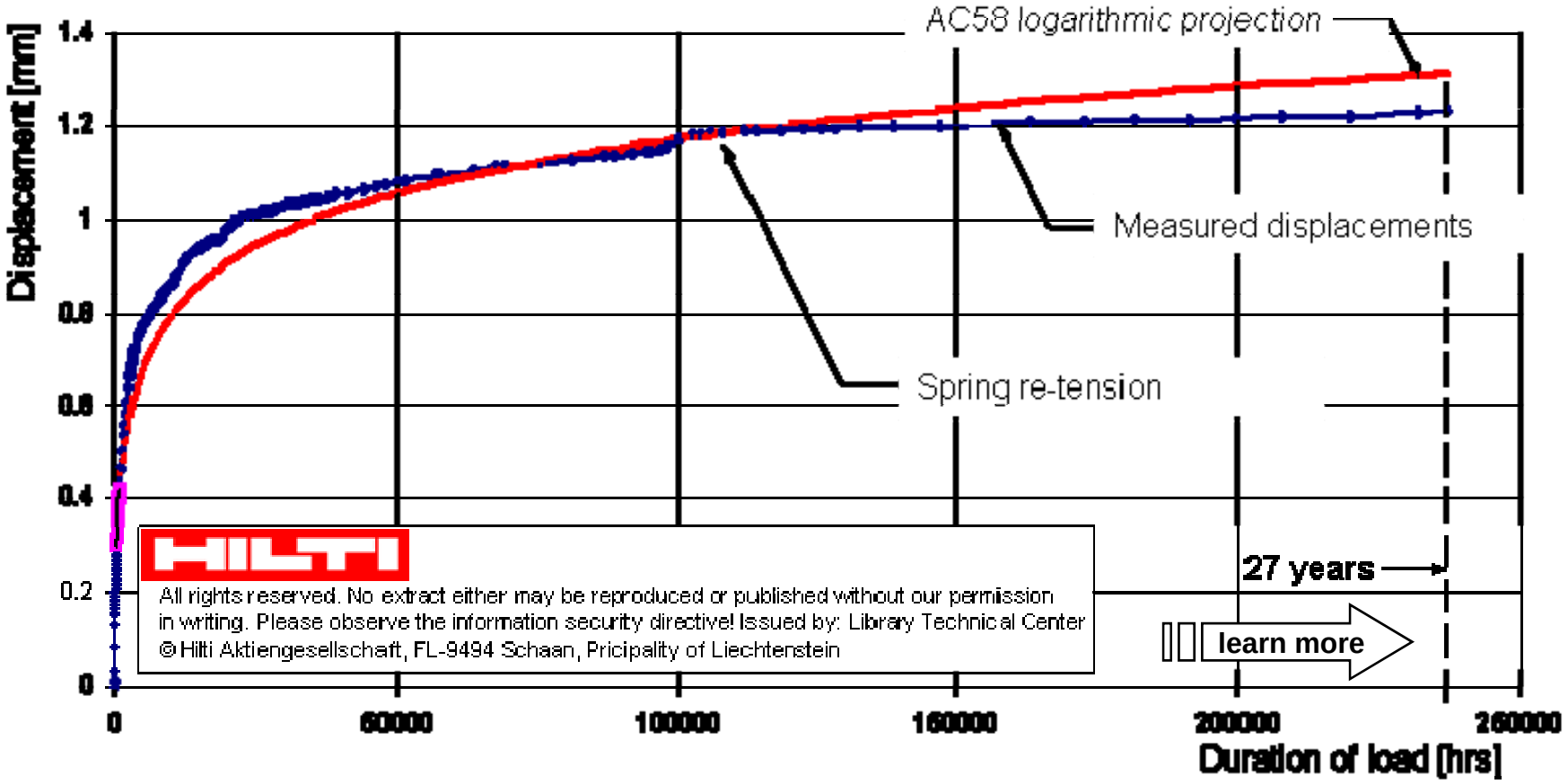
What is creep?

Creep basics:

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



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

Content

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

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."

Determine sustained tension load:
=> Ultimate load at 70F → N_u x 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):
=> $s_{total} = c \cdot \ln t + b$

Conditions of acceptance $s_{total} < s_u$

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

passed:
Safety factor 4
Allowable load
= N_u / 4

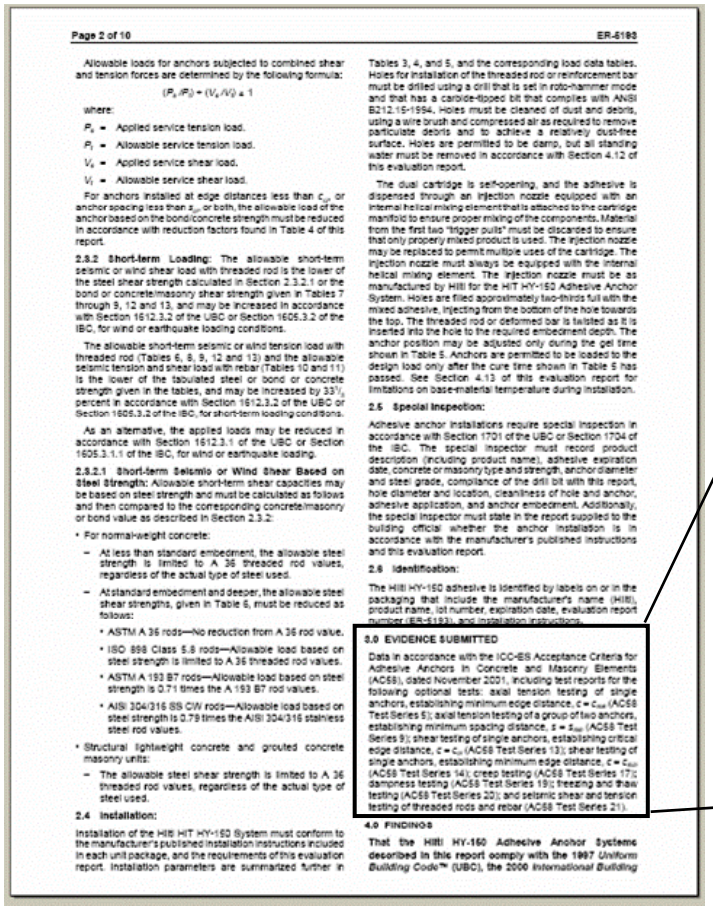
A product could get an AC58 ICC-ESR without passing a creep test (optional!).
The product was consequently limited to short term load.

Product <u>not</u> permitted for sustained loads

Product permitted for sustained loads

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:



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Allowable loads for anchors subjected to combined shear and tension forces are determined by the following formula:

$$(P_s/P_t) + (V_s/V_t) \leq 1$$

where:

P_s = Applied service tension load.

P_t = Allowable service tension load.

V_s = Applied service shear load.

V_t = Allowable service shear load.

For anchors installed at edge distances less than c_{cr}, or anchor spacing less than s_{cr}, or both, the allowable load of the anchor based on the bond/concrete strength must be reduced in accordance with reduction factors found in Table 4 of this report.

2.3.2 Short-term Loading: The allowable short-term seismic or wind shear load with threaded rod is the lower of the steel shear strength calculated in Section 2.3.2.1 or the bond or concrete/masonry shear strength given in Tables 7 through 9, 12 and 13, and may be increased in accordance with Section 1612.3.2 of the UBC or Section 1605.3.2 of the IBC, for wind or earthquake loading conditions.

The allowable short-term seismic or wind tension load with threaded rod (Tables 6, 8, 9, 12 and 13) and the allowable seismic tension and shear load with rebar (Tables 10 and 11) is the lower of the tabulated steel or bond or concrete strength given in the tables, and may be increased by 33⅓ percent in accordance with Section 1612.3.2 of the UBC or Section 1605.3.2 of the IBC, for short-term loading conditions.

As an alternative, the applied loads may be reduced in accordance with Section 1612.3.1 of the UBC or Section 1605.3.1.1 of the IBC, for wind or earthquake loading.

2.3.2.1 Short-term Seismic or Wind Shear Based on Steel Strength: Allowable short-term shear capacities may be based on steel strength and must be calculated as follows and then compared to the corresponding concrete/masonry or bond value as described in Section 2.3.2:

- For normal-weight concrete:
  - At less than standard embedment, the allowable steel strength is limited to A 36 threaded rod values, regardless of the actual type of steel used.
  - At standard embedment and deeper, the allowable steel shear strengths, given in Table 6, must be reduced as follows:
    - ASTM A 36 rods—No reduction from A 36 rod value.
    - ISO 898 Class 5.8 rods—Allowable load based on steel strength is limited to A 36 threaded rod values.
    - ASTM A 193 B7 rods—Allowable load based on steel strength is 0.71 times the A 193 B7 rod values.
    - AISI 304/316 SS CW rods—Allowable load based on steel strength is 0.79 times the AISI 304/316 stainless steel rod values.
- Structural lightweight concrete and grouted concrete masonry units:
  - The allowable steel shear strength is limited to A 36 threaded rod values, regardless of the actual type of steel used.

2.4 Installation:

Installation of the Hilti HIT HY-150 System must conform to the manufacturer's published installation instructions included in each unit package, and the requirements of this evaluation report. Installation parameters are summarized further in Tables 3, 4, and 5, and the corresponding load data tables. Holes for installation of the threaded rod or reinforcement bar must be drilled using a drill that is set in roto-hammer mode and that has a carbide-tipped bit that complies with ANSI B212.15-1994. Holes must be cleaned of dust and debris, using a wire brush and compressed air as required to remove particulate debris and to achieve a relatively dust-free surface. Holes are permitted to be damp, but all standing water must be removed in accordance with Section 4.12 of this evaluation report.

The dual cartridge is self-opening, and the adhesive is dispensed through an injection nozzle equipped with an internal helical mixing element that is attached to the cartridge manifold to ensure proper mixing of the components. Material from the first two "trigger pulls" must be discarded to ensure that only properly mixed product is used. The injection nozzle may be replaced to permit multiple uses of the cartridge. The injection nozzle must always be equipped with the internal helical mixing element. The injection nozzle must be as manufactured by Hilti for the HIT HY-150 Adhesive Anchor System. Holes are filled approximately two-thirds full with the mixed adhesive, injecting from the bottom of the hole towards the top. The threaded rod or deformed bar is twisted as it is inserted into the hole to the required embedment depth. The anchor position may be adjusted only during the gel time shown in Table 5. Anchors are permitted to be loaded to the design load only after the cure time shown in Table 5 has passed. See Section 4.13 of this evaluation report for limitations on base-material temperature during installation.

2.5 Special Inspection:

Adhesive anchor installations require special inspection in accordance with Section 1701 of the UBC or Section 1704 of the IBC. The special inspector must record product description (including product name), adhesive expiration date, concrete or masonry type and strength, anchor diameter and steel grade, compliance of the drill bit with this report, hole diameter and location, cleanliness of hole and anchor, adhesive application, and anchor embedment. Additionally, the special inspector must state in the report supplied to the building official whether the anchor installation is in accordance with the manufacturer's published instructions and this evaluation report.

2.6 Identification:

The Hilti HY-150 adhesive is identified by labels on or in the packaging that include the manufacturer's name (Hilti), product name, lot number, expiration date, evaluation report number (ER-5193), and installation instructions.

3.0 EVIDENCE SUBMITTED

Data in accordance with the ICC-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, $c = c_{min}$ (AC58 Test Series 5); axial tension testing of a group of two anchors, establishing minimum spacing distance, $s = s_{min}$ (AC58 Test Series 9); shear testing of single anchors, establishing critical edge distance, $c = c_{cr}$ (AC58 Test Series 13); shear testing of single anchors, establishing minimum edge distance, $c = c_{min}$ (AC58 Test Series 14); creep testing (AC58 Test Series 17); dampness testing (AC58 Test Series 19); freezing and thaw testing (AC58 Test Series 20); and seismic shear and tension testing of threaded rods and rebar (AC58 Test Series 21).

4.0 FINDINGS

That the Hilti HY-150 Adhesive Anchor Systems described in this report comply with the 1997 *Uniform Building Code*™ (UBC), the 2000 *International Building*

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, $c = c_{min}$ (AC58 Test Series 5); axial tension testing of a group of two anchors, establishing minimum spacing distance, $s = s_{min}$ (AC58 Test Series 9); shear testing of single anchors, establishing critical edge distance, $c = c_{cr}$ (AC58 Test Series 13); shear testing of single anchors, establishing minimum edge distance, $c = c_{min}$ (AC58 Test Series 14); creep testing (AC58 Test Series 17); dampness testing (AC58 Test Series 19); freezing and thaw testing (AC58 Test Series 20); and seismic shear and tension testing of threaded rods and rebar (AC58 Test Series 21).

Evidence Submitted?
ESR → Section 6
ER → Section 3

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)

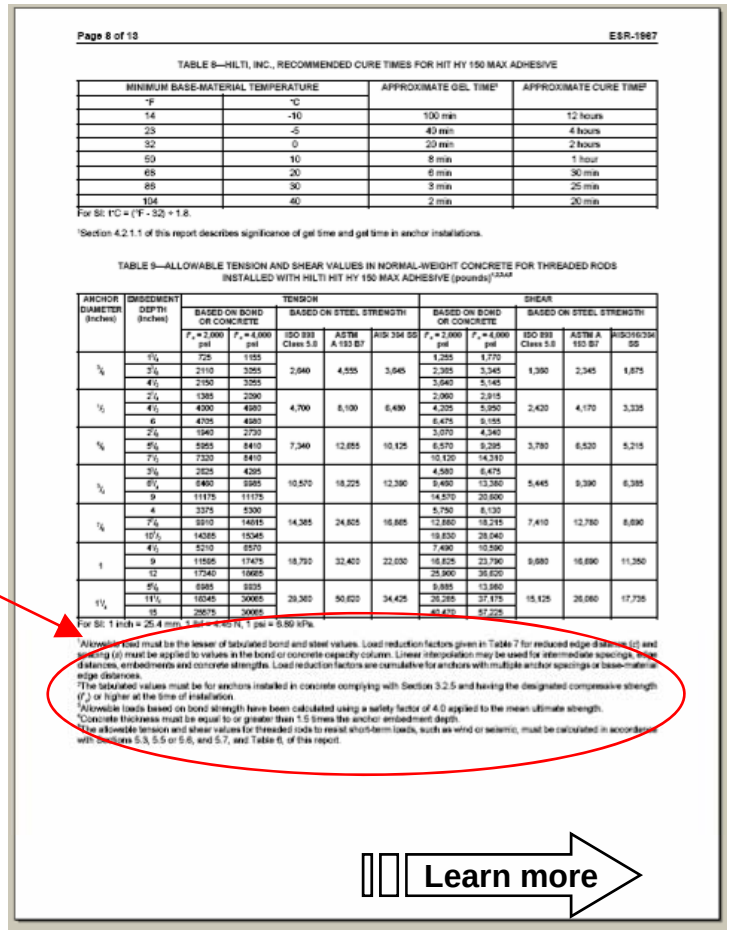

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TABLE 8—HILTI, INC., RECOMMENDED CURE TIMES FOR HIT HY 150 MAX ADHESIVE

MINIMUM BASE-MATERIAL TEMPERATURE		APPROXIMATE GEL TIME[1]	APPROXIMATE CURE TIME[2]
°F	°C		
14	-10	100 min	12 hours
23	-5	40 min	4 hours
32	0	20 min	2 hours
50	10	8 min	1 hour
68	20	6 min	30 min
86	30	3 min	25 min
104	40	2 min	20 min

For SI: T°C = (°F - 32) ÷ 1.8.

[1]Section 4.2.1.1 of this report describes significance of gel time and gel time in anchor installations.

TABLE 9—ALLOWABLE TENSION AND SHEAR VALUES IN NORMAL-WEIGHT CONCRETE FOR THREADED RODS INSTALLED WITH HILTI HIT HY 150 MAX ADHESIVE (pounds)[1,2,3,4,5,6]

ANCHOR DIAMETER (inches)	EMBEDMENT DEPTH (inches)	TENSION					SHEAR				
		BASED ON BOND OR CONCRETE		BASED ON STEEL STRENGTH			BASED ON BOND OR CONCRETE		BASED ON STEEL STRENGTH		
		f'_c = 2,000 psi	f'_c = 4,000 psi	ISO 898 Class 5.8	ASTM A 193 B7	AISI 304 SS	f'_c = 2,000 psi	f'_c = 4,000 psi	ISO 898 Class 5.8	ASTM A 193 B7	AISI316/304 SS
⅜	1¼	725	1155	2,040	4,555	3,645	1,255	1,770	1,360	2,345	1,875
	3⅛	2110	3365				2,305	3,345			
	4½	2150	3365				3,640	5,145			
½	2¼	1385	2090	4,700	8,100	6,480	2,060	2,915	2,420	4,170	3,335
	4½	4000	4980				4,205	5,950			
	6	4705	4980				6,475	9,155			
⅝	2⅝	1940	2730	7,340	12,655	10,125	3,070	4,340	3,780	6,520	5,215
	5⅛	5355	8410				6,570	9,295			
	7½	7320	8410				10,120	14,310			
¾	3⅜	2826	4295	10,570	18,225	12,390	4,580	6,475	5,445	9,390	6,385
	6¼	6490	9985				9,490	13,380			
	9	11175	11175				14,570	20,600			
⅞	4	3375	5300	14,385	24,805	16,865	5,750	8,130	7,410	12,780	8,690
	7⅛	9310	14615				12,660	18,215			
	10½	14365	15345				19,830	28,040			
1	4½	5210	8570	18,790	32,400	22,030	7,490	10,590	9,680	16,690	11,350
	9	11595	17475				16,825	23,790			
	12	17540	19665				25,900	36,620			
1¼	5⅝	8985	9935	29,360	50,620	34,425	9,885	13,980	15,125	26,060	17,735
	11¼	16345	30965				26,285	37,175			
	15	29875	30965				40,470	57,225			

For SI: 1 inch = 25.4 mm, 1 lbf = 4.45 N, 1 psi = 6.89 kPa.

[1]Allowable load must be the lesser of tabulated bond and steel values. Load reduction factors given in Table 7 for reduced edge distance (c) and spacing (s) must be applied to values in the bond or concrete capacity column. Linear interpolation may be used for intermediate spacings, edge distances, embedments and concrete strengths. Load reduction factors are cumulative for anchors with multiple anchor spacings or base-material edge distances.

[2]The tabulated values must be for anchors installed in concrete complying with Section 3.2.5 and having the designated compressive strength (f'_c) or higher at the time of installation.

[3]Allowable loads based on bond strength have been calculated using a safety factor of 4.0 applied to the mean ultimate strength.

[4]Concrete thickness must be equal to or greater than 1.5 times the anchor embedment depth.

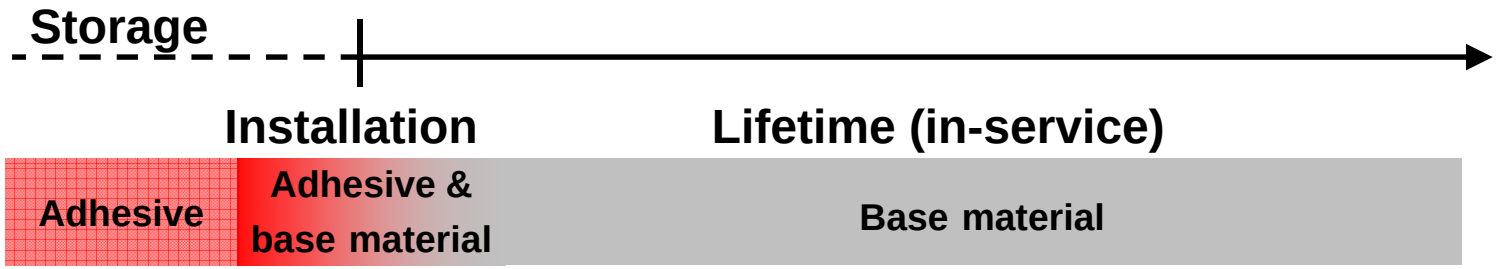
[5]The allowable tension and shear values for threaded rods to resist short-term loads, such as wind or seismic, must be calculated in accordance with Sections 5.3, 5.5 or 5.6, and 5.7, and Table 6, of this report.

Learn more

Content

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

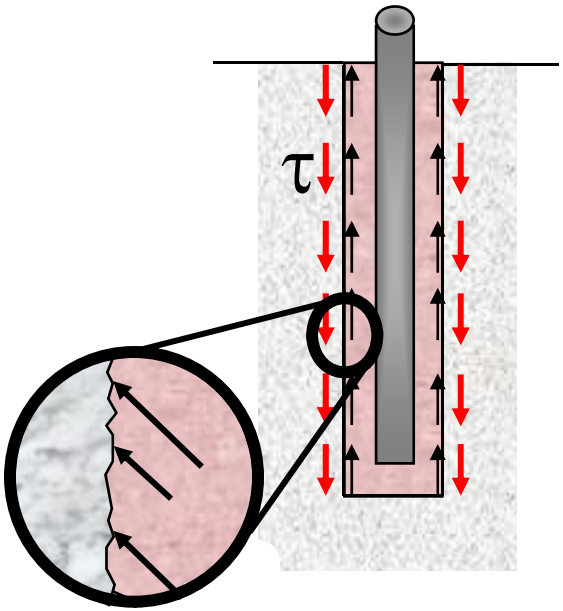
Installation
Dispensing forces
Working times
Cure time
Load values

In-Service
Short Term
Long Term (creep)
Fire

Temperature must be considered for Adhesive Anchoring Systems for the various stages of the fastening's lifecycle

Content

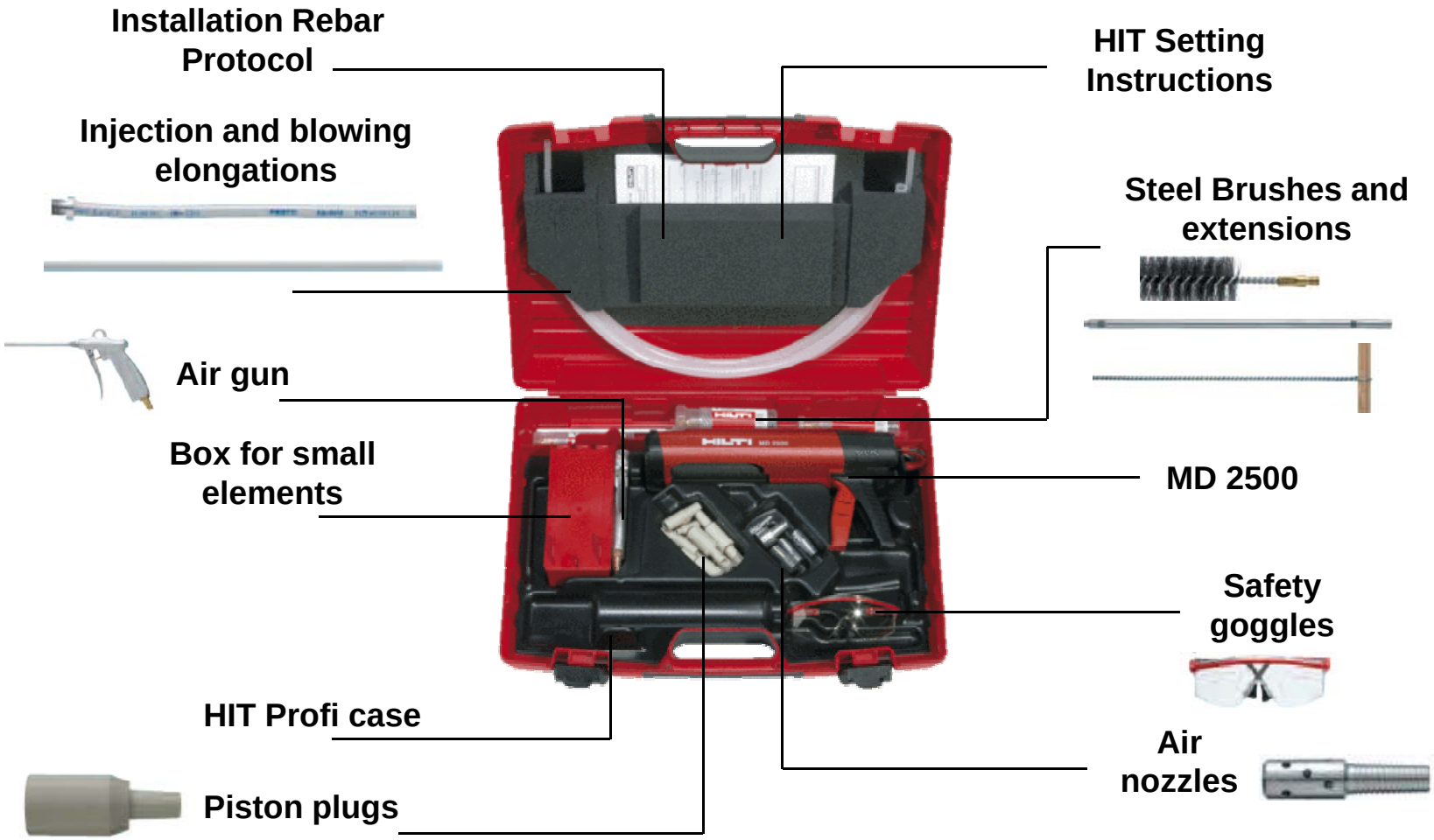
Performance of adhesive anchors are related to installation procedures and accessories



Bond Value / Installation accuracy

Blowing out	Brushing	Injecting
Blow-outl pump	Bristle Brush	Injection nozzle
Compressed-air gun	Steel Brush	Injection extension
Compressed-air gun + air nozzle		Piston plugs

PROFI Kits Help Ensure Proper Installation



Content

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)

Hilti's current product portfolio passed an AC58 creep test

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→ Acrylate: shorter curing time (Fast Cure)
- Polyaddition→ 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)

Content

What changes with AC308 - what are the reasons?

AC58 evolved into AC308. The main developments:

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

AC308 creep test is mandatory and published technical data directly depend on the result of creep tests

AC58 → AC308		Benefit
No Anchor Categories	Established Anchor Categories	Categories are related to system's sensitivity to hole preparation and gives engineers transparency to system reliability.
Only evaluates onse size (1/2") and one embedment (4-1/2")	Test full range of embedments to determine a system's sensitivity to cleaning	A system's sentivity to hole cleaning is adequately evaluated
Requires continuous inspection for all adhesive anchors	Allows for periodic inspection	Systems proven to be reliable save time and money for the project.
No inspection procedure required	Manufaturer's must submit inspection procedures for adhesive anchors	Guidance on proper inspection of anchors

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**

Content

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