POST-INSTALLED REINFORCING IN FIRE CONDITIONS

September 2024

1.0 POST-INSTALLED REINFORCING IN FIRE CONDITIONS FOR CONCRETE CONSTRUCTION

Fires are unfortunately an occurrence that some buildings are exposed to over their service life. It is known that the fire can do significant damage to both the non-structural and structural elements of a building during a fire. The model building codes are constructed to allow the occupants to exit safely and hopefully to limit the damage from the fire. Both the International Building Code (IBC) in the United States and the National Building Code of Canada (NBC-C) have provisions to create fire barriers to limit fire spread if a fire should break out.

In concrete and masonry structures, engineers today can use ACI/TMS 216.1 **Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies** to examine how the building structural elements will be affected when exposed to the high temperatures in a fire. ACI 216.1 provides information on the design of concrete walls, floors, and roofs, which make up the primary fire rated assemblies in a structure, as well as providing information on the effects of the fire on steel reinforcing, and the design of concrete beams and columns. There are also design considerations for steel columns encased in concrete and provisions for fire consideration in masonry structures.

However, there are no provisions within ACI 216.1 or other reference codes in the United States or Canada that considers the effects of fire on post-installed anchors such as post-installed reinforcing with adhesive anchoring systems that is used to develop the rebar just like cast-in rebar. Designing post-installed anchors for fire exposure has been more common in Europe, primarily due to the high number of tunnels where fires are extremely dangerous. In Europe, there are testing and design standards which are used by designers to evaluate post-installed anchors in fire conditions.

In conjunction with ACI 216.1 and a new test and evaluation acceptance criteria implemented by ICC Evaluation Services (ICC-ES), this document is intended to provide a methodology that designers using ACI 318 or CSA A23.3 can use to evaluate post-installed rebar connections with Hilti adhesives for rebar development during a fire event.

ICC-ES **Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements** (AC308) was updated in 2015 so that post-installed rebar with adhesive could be qualified to show equivalence with cast-in rebar for development length calculations. Hilti has qualified HIT-RE 500 V3 with ICC-ES for use with ACI 318 Chapter 25 rebar development equations within ESR 3814. Refer to the Hilti North American Product Technical Guide: Post-Installed Reinforcing Guide, dated November 2022 (Rebar Tech Guide), for more information on designing post-installed rebar connections with Hilti adhesive anchors.

AC308 was subsequently updated in 2022 with testing provisions for fire exposure. Hilti has performed the new tests for fire evaluation in AC308 and ESR-3814 has been updated with data for use in fire conditions for post-installed rebar development connections. Refer to ESR-3814 and Section 4.0 of this document for data related to tests in fire conditions with HIT-RE 500 V3. For the first time, designers and building officials have a tool related to performance of post-installed anchors in fire for the United States or Canada and do not have to rely on European information.

In addition, Hilti has a new adhesive product, HIT-FP 700 R, which is a brand-new injectable cementitious adhesive which has very little sensitivity to high heat. Cementitious, inorganic adhesives are not currently recognized by AC308, so it is not possible to receive an evaluation report to AC308. However, HIT-FP 700 R has been tested to all of the provisions of AC308 including the new fire tests and the technical data for rebar development is provided in Section 3.0 of this document for designs in fire and non-fire (ambient temperature) conditions.

2.0 DESIGN FOR REBAR DEVELOPMENT IN FIRE CONDITIONS

The design methodology in this section is to be used in conjunction with standard rebar development calculations in ACI 318 Chapter 25 and CSA A23.3 Chapter 12 and with fire exposure based on a time to temperature curve established in ASTM E119 **Standard Test Methods for Fire Tests of Building Construction and Materials**. In general, the design will determine whether the development length needed at ambient temperature will need to be increased due to fire exposure to account for the potential loss in bond stress in the concrete that has been heated.

For the design the following information is needed:

- The development length of the post-installed rebar at ambient temperature.
- The fire duration rating of the connection, such as 30, 60, 90, 120, 180, or 240 minutes.
- The temperature in the concrete at the specific concrete cover distance of the rebar.

With this information, and with the post-installed adhesive test data from the AC308 fire tests in this document for either HIT-FP 700 R or HIT-RE 500 V3 the development length needed for the fire condition can be determined.

2.1 DETERMINE EQUIVALENT BOND STRESS AT AMBIENT TEMPERATURE

At ambient temperature (no fire consideration), development length for post-installed adhesives with rebar is calculated as follows:

ACI 318 Chapter 25 Eq. 25.4.2.3:

$$\ell_d = \left[\frac{3}{40} \times \frac{f_y}{\lambda \sqrt{f'_c}} \times \frac{\psi_t \, \psi_e \, \psi_s \, \psi_g}{\frac{c_b + k_{tr}}{d_b}} \right] d_b \quad \text{(in)}$$

CSA A23.3 12.2.2 Eq. 12-1:

$$\ell_d = 1.15 \frac{k_1 \, k_2 \, k_3 \, k_4}{d_{cs} + k_{tr}} \frac{f_y}{\sqrt{f'_c}} A_b$$

Refer to ACI 318, CSA A23.3, or the Rebar Tech Guide for more information on calculating development length with Hilti adhesive anchors including HIT-FP 700 R and HIT-RE 500 V3.

The development length calculated above is considered the ambient temperature development length. To determine an equivalent bond stress for the adhesive at ambient temperature, τ_{equiv}, divide the yield capacity of the bar by the surface area of the rebar at the ambient temperature development length:

$$\tau_{equiv} = \frac{f_y \cdot A_b}{\pi \cdot d_b \cdot \ell_d}$$

The equation for τ_{equiv}, is applicable for both ACI and CSA calculations.

2.2 DETERMINE THE TEMPERATURE IN THE CONCRETE UNDER FIRE CONDITIONS

The next step is to determine what the temperature in the concrete, θ, is based on the fire rating, the concrete cover, and knowing the type of concrete aggregates used. In the United States and Canada, typical fire exposure for buildings regulated by the IBC or NBC-C is based on a time to temperature curve established in ASTM E119. ACI 216.1 provides guidance on the temperature in the concrete based on the concrete cover, the fire test time (fire rating), and the aggregate type.

For fire exposure on one side of a concrete wall, floor, or roof, refer to ACI 216.1 Figures 4.4.2.2.1a(a), (b), and (c), for carbonate aggregate, siliceous aggregate, and semi-lightweight aggregate respectively. The above noted figures are provided below for reference. Each figure shows concrete cover curves, with the Temperature (F) on left vertical axis and Temperature (C) on right vertical axis. The horizontal axis is the fire time in minutes (fire rating or duration). From the specific fire rating and concrete cover, the temperature at the location of the rebar, θ, can be determined.

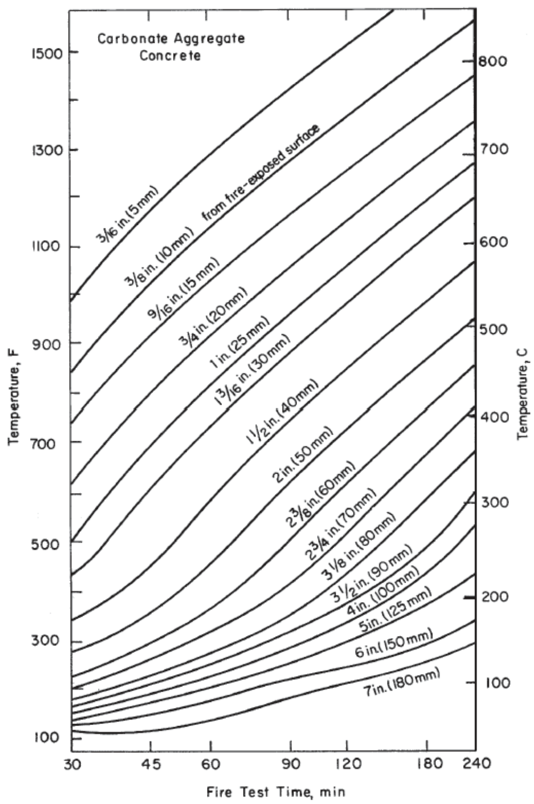


Figure 4.4.2.2.1a(a) — Temperatures within slabs during ASTM E119 fire tests — carbonate aggregate concrete.

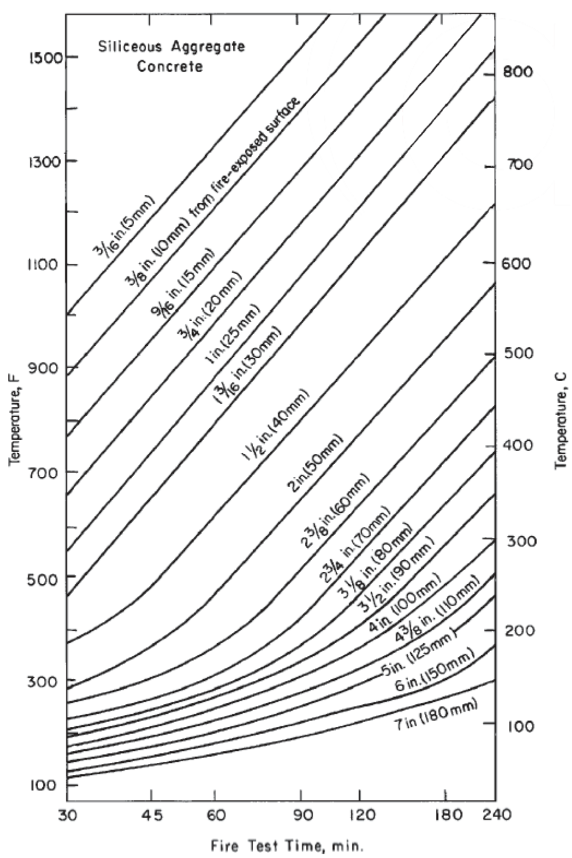


Figure 4.4.2.2.1a(b) —Temperatures within slabs during ASTM E119 fire tests — siliceous aggregate concrete.

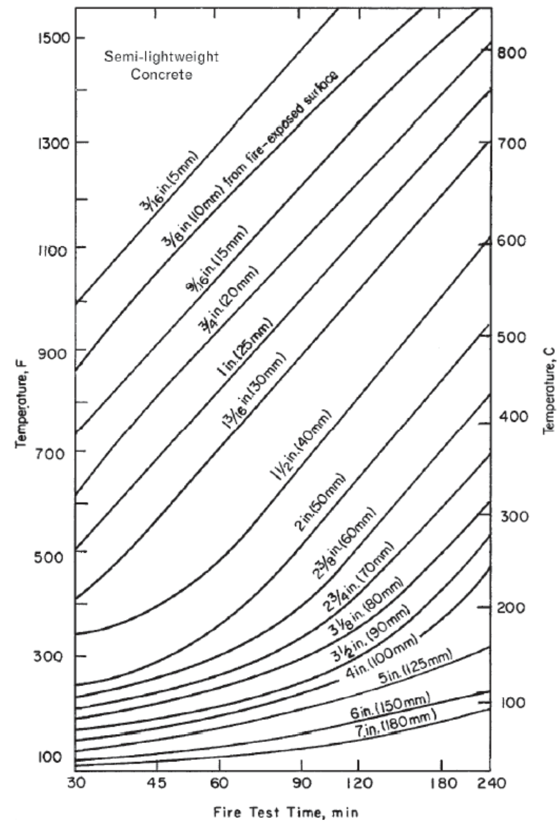


Figure 4.4.2.2.1a(c) — Temperatures within slabs during ASTM E119 fire tests — semi-lightweight aggregate concrete.

Refer to ACI 216.1 for other graphs showing concrete temperatures for beam reinforcing and other conditions.

For applications with a constant cover dimension over the length of the rebar, the temperature in the concrete will be the same over the entire length of the embedded portion of the post-installed rebar. Figure 1 below shows an example of a roof slab extension with fire exposure on one side and the associated temperature distribution over the bond length of the of the post-installed rebar.

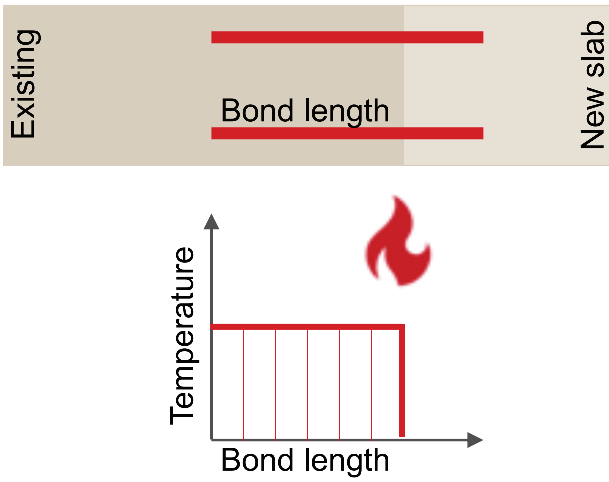


Figure 1 — Example of constant temperature over the bond length of a post-installed rebar.

For applications where the cover distance will vary along the length of the embedded rebar, the temperature will also vary along the length of the rebar. Figure 2 below shows an example of a concrete floor slab to wall connection with fire exposure on one side resulting in a variable temperature distribution over bond length of the of the post-installed rebar.

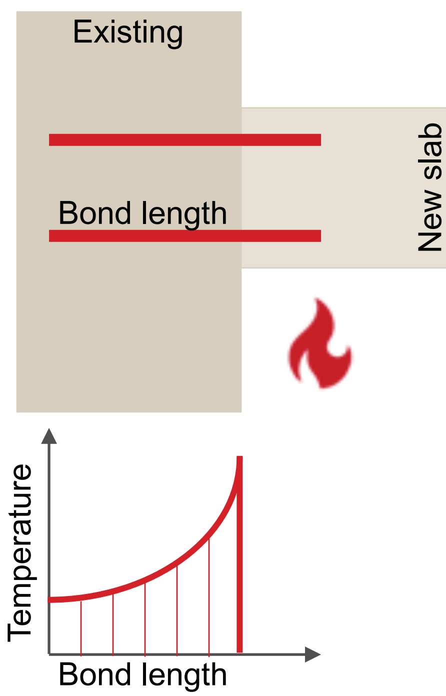


Figure 2 — Example of variable temperature over the bond length of a post-installed rebar.

The resulting determination of the temperature for calculation of the subsequent bond stress can be done in one of two ways.

1) The worst-case temperature based on the smallest cover distance can be used conservatively, or

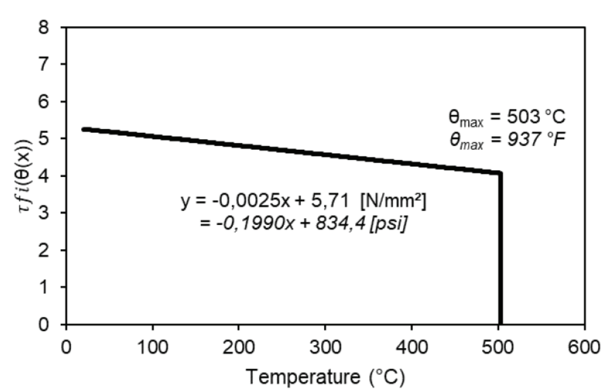
2) It is possible to use smaller increments, or segments, ℓ_{seg}, and determine multiple temperatures along the length of the rebar. The designer should determine the value of ℓ_{seg} to be used for the application (i.e. 10 mm) and then record the worst case concrete temperature at each increment of ℓ_{seg} over the length of the rebar. The smaller the value of ℓ_{seg} will lead to more temperature checks in Figure 4.4.2.2.1a but will lead to a less conservative development length in the fire condition when larger values of ℓ_{seg} are used.

2.3 DETERMINE BOND STRESS RELATED TO TEMPERATURE

Once the temperature in the concrete, θ, at the rebar is determined, the next step is to determine what the bond stress is for the adhesive at that concrete cover temperature. The reduction in the bond stress under high temperatures is different for every adhesive anchor system and should be tested per the new fire provisions of AC308.

Hilti has two products tested to the new AC308 fire provisions. Refer to Section 3.0 of this document for the technical data for fire conditions for HIT-FP 700 R. Refer to Section 4.0 of this document for the technical data for fire conditions for HIT-RE 500 V3 which is also provided in ESR 3814.

For both products, a fire data curve is provided showing the relationship of temperature, θ, and bond stress, $\tau_{fire(\theta)}$. Refer to Figure 5 for HIT-FP 700 R and Figures 9 and 10 for HIT-RE 500 V3. The figure below is from Figure 5 for HIT-FP 700 R.



$$\bar{\tau}_{fire(\theta)} = -0.199 \cdot \theta + 834.4\ [psi]$$

$$\bar{\tau}_{fire(\theta max)} = 0.0\ ;\ \theta_{max} = 937\ °F$$

Using the concrete temperature determined from Figure 4.4.2.2.1a of ACI/TMS 216.1 as θ determine the corresponding bond stress under fire conditions at that temperature, $\tau_{fire(\theta)}$. This can then be determined from the graph, or by plugging θ into the provided equations for the Hilti adhesive product.

The maximum temperature, θ_{max}, is the highest temperature permitted for the adhesive and once beyond that temperature the product is assumed to have no bond stress. For constant temperature along the length of the rebar, if the concrete temperature at the bar exceeds θ_{max}, then additional concrete cover will be needed. For variable temperature along the length of the rebar, there may be segments where θ_{max} is exceeded and $\tau_{fire(\theta)}$ is effectively zero and would not contribute to the overall bond stress in that section of the rebar for fire exposure, and the overall bond stress would be taken from the segments in the concrete where θ is less than θ_{max}.

2.4 DETERMINE DEVELOPMENT LENGTH NEEDED FOR FIRE CONDITION

For constant temperature along the length of the rebar the value of $\tau_{fire(\theta)}$ determined from the charts will be the value that is then compared to the value of τ_{equiv} calculated from the development length at the ambient temperature. From this, the development length needed for the fire condition can be calculated as follows:

$$\ell_{d,fire} = \frac{\tau_{equiv}}{\tau_{fire(\theta)}} \cdot \ell_d$$

Note: If the development length for the fire condition, $\ell_{d,fire}$, is less than the ambient temperature development length, ℓ_d, then the ambient temperature development length, ℓ_d, should be used. Effectively, as long as the value of $\tau_{fire(\theta)}$ is greater than the value of τ_{equiv} along the entire length of the rebar then the ambient temperature development length will control.

For variable temperature along the length of the rebar, the process is more iterative. The value of $\tau_{fire(\theta),seg}$ will need to be determined at each of the equal length segments, ℓ_{seg}, along the length of the bond length of the rebar, for a total number of segments, n_{seg}. Then, the value of $\tau_{fire(\theta),seg}$ for each segment is multiplied by the surface area of the bar in each segment to give a segment bond strength $N_{a,fire,seg(\theta)}$. The segment bond strengths can then be summed up for a total bond strength, $N_{a,fire}$. This total bond strength needs to be greater than the yield stress of the rebar.

$$N_{a,fire} = \sum_{i=1}^{n_{seg}} \pi \cdot d_b \cdot \ell_{leg,i} \cdot \tau_{fire(\theta),segi} \geq f_y \cdot A_{se,N}$$

Once the total number of segments is determined then the final development length needed for the fire condition can be calculated.

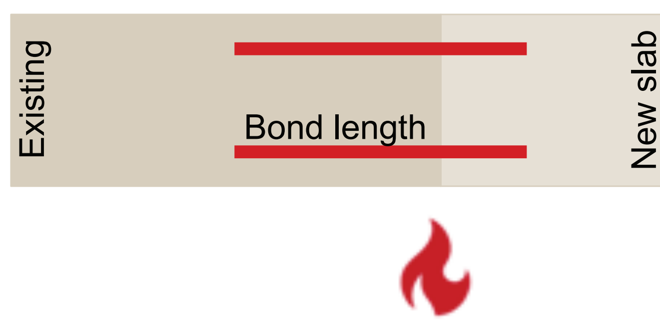
$$\ell_{d,fire} = n_{seg} \cdot \ell_{seg}$$

Note: The value of $\tau_{fire(\theta)}$ in any individual segment cannot exceed τ_{equiv} determined from Section 2.1. Thus a development length for the fire condition will never be smaller than the development length determined at ambient temperature. Similar to the calculation for constant temperature along the length of the rebar, as long as the value of $\tau_{fire(\theta)}$ in the warmest section of the concrete is greater than the value of τ_{equiv} then the ambient temperature development length will control and the iterative calculation above does not need to be performed.

Similar to determining the temperature at a specific concrete cover for variable concrete temperature, the smaller the value of ℓ_{seg} will lead to more calculations of $\tau_{fire(\theta),seg}$ but will lead to a less conservative development length in the fire condition when larger values of ℓ_{seg} are used.

2.5 DESIGN EXAMPLE WITH CONSTANT TEMPERATURE ALONG BOND LENGTH

The following design example is for a floor slab extension in 4,000 psi normal weight concrete with carbonate aggregate.



Given:

- ASTM A615 Gr. 60 reinforcement, #6 rebar installed with HIT-FP 700 R
- Concrete cover, c_b = 2-inch
- Non-seismic floor loads only

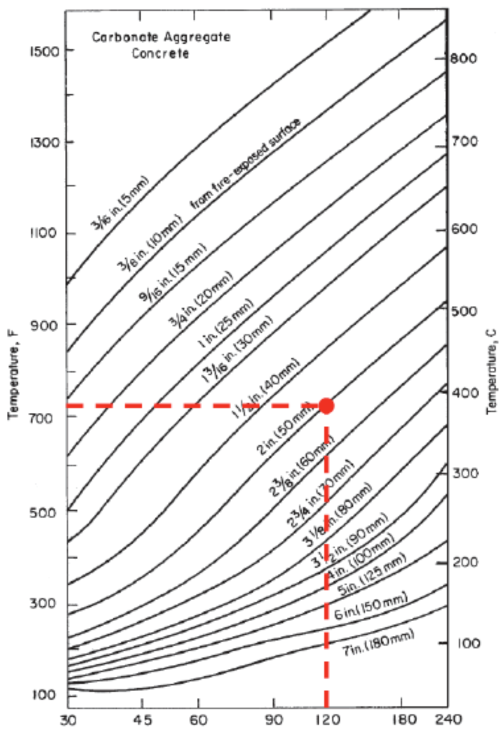
Step 1: Determine ambient temperature development length and equivalent bond stress:

- From Table 3 of Section 3.0 (or ACI 318 Chapter 25 Eq. 25.4.2.3) the development length for HIT-FP 700 R with #6 rebar is determined:

- ℓ_d = 21.6-inch → use 22-inch
- $\tau_{equiv} = \dfrac{f_y \cdot A_b}{\pi \cdot d_b \cdot \ell_d} = \dfrac{60{,}000\text{ psi} \cdot 0.44\text{in}^2}{\pi \,.\, 0.750\text{in} \,.\, 22\text{in}} = 509\text{psi}$

Step 2: Determine temperature in concrete under fire conditions:

- Using ACI/TMS 216.1 Figure 4.4.2.2.1a(a) with 2-inch cover the temperature in the concrete is determined:
- θ ≈ 725 °F



Step 3: Determine the bond stress related to the concrete temperature in fire condition:

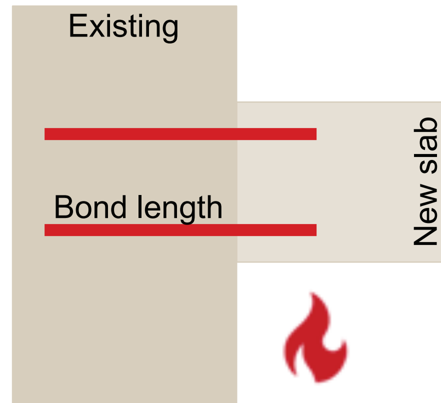
- From the equations of Figure 5 of Section 3.0 the bond stress at θ is determined:
- $\tau_{fire(\theta} = -0.1990 \cdot \theta + 834.4$
- $\tau_{fire(\theta} = -0.1990 \cdot 725 + 834.4 = 690$ psi

Step 4: Determine the development length needed for the fire condition:

- $\ell_{d,fire} = \dfrac{\tau_{equiv}}{\tau_{fire(\theta)}} \cdot \ell_d = \dfrac{509\text{ psi}}{690\text{ psi}} \cdot 22\text{in} = 16.2\text{in}$
- $\ell_{d,fire} < \ell_d$ ∴ ambient temperature development length should be used
- $\ell_{d,fire} = \ell_d$ = 22-inch
- As a shortcut, since the value of $\tau_{fire(\theta)}$ = 690 psi (where c_b = 50mm in Step 3) is greater than τ_{equiv} = 509 psi, it could have already been determined that the ambient temperature development length controlled and no additional embedment depth is needed for the fire condition.

2.6 DESIGN EXAMPLE WITH VARIABLE TEMPERATURE ALONG REINFORCEMENT

The following design example is for a floor slab connected to a shear wall in 4,000 psi normal weight concrete with carbonate aggregate.



Given:

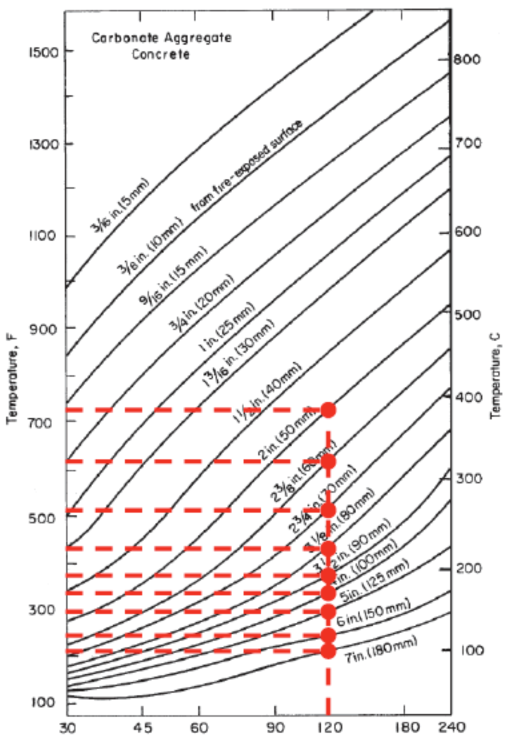
- ASTM A615 Gr. 60 reinforcement, #6 rebar installed with HIT-FP 700 R
- Concrete cover, c_b, starts at 2” (50 mm) and then varies with embedment
- Non-seismic floor loads only

Step 1: Determine ambient temperature development length and equivalent bond stress:

- From Table 3 of Section 3.0 (or ACI 318 Chapter 25 Eq. 25.4.2.3) the development length for HIT-FP 700 R with #6 rebar is determined:
- ℓ_d = 21.6-inch → use 22-inch
- $\tau_{equiv} = \dfrac{f_y \cdot A_b}{\pi \cdot d_b \cdot \ell_d} = \dfrac{60{,}000\text{ psi} \cdot 0.44\text{in}^2}{\pi \cdot 0.750\text{in} \cdot 22\text{in}} = 509\text{psi}$

Step 2: Determine temperature in concrete under fire conditions:

- Using ACI/TMS 216.1 Figure 4.4.2.2.1a(a) the temperature at various concrete cover depths needs to be determined as an iterative evaluation of temperature and bond will be performed. Since the new slab already has a 2-inch cover, start with 2-inch cover and use ℓ_{seg} = 10mm to determine the temperature in the concrete at each segment, up to 180mm (7-inch):



- From the graph above we get the following temperature gradient:

Conc. cover c_b mm	Conc. temp. θ °F
60	620
70	513
80	433
90	380
100	340
110	300
120	300
130	253
140	253
150	253
160	220
170	220
≥ 180	220

Step 3: Determine the bond stress related to the concrete temperature in fire condition:

- From the equations of Figure 5 of Section 3.0 the bond stress, $\tau_{fire(\theta)}$, is determined for each segment:
- $\tau_{fire(\theta)} = -0.1990 \cdot \theta + 834.4$
- $\theta_{max} = 937°F$

Conc. cover c_b mm	Conc. temp. θ °F	Bond stress $\tau_{fire(\theta)}$ psi
60	620	711
70	513	732
80	433	748
90	380	759
100	340	767
110	300	775
120	300	775
130	253	784
140	253	784
150	253	784
160	220	791
170	220	791
≥ 180	220	791

Note: The value of $\tau_{fire(\theta)}$ for each segment is greater than τ_{equiv} = 509 psi from Step 1. In Step 4 below we will limit the segment bond stress $\tau_{fire(\theta)}$ accordingly.

Step 4: Determine the development length needed for the fire condition:

- Determine the yield strength of the rebar:
- $N_{sa,y} = f_y \cdot A_{se,N}$ = 60,000ksi · 0.44in^2 = 26,400lb.Determine the total bond strength by summing up the segment bond stresses and multiplying by the bar area:

- $N_{a,fire} = \sum_{i=1}^{n_{seg}} \pi \cdot d_b \cdot \ell_{seg} \cdot \tau_{fire(\theta),segi}$

- Using the bond stress at each segment, sum up the segment length bond strengths until the rebar yield strength is reached. In the table below for each 10mm (0.394-inch) segment a bond strength, $N_{a,fire(\theta)}$, is calculated:
- $N_{a,fire(\theta)} = \pi \cdot d_b \cdot \ell_{seg} \cdot \tau_{fire(\theta),segi}$

Conc. cover c_b mm	Bar length $\ell_{d,fire}$ in	Conc. temp. θ °F	Bond stress $\tau_{fire(\theta)}$ psi	Bond strength $N_{a,fire(\theta)}$ lb.
60	0.36	620	509	472
70	0.76	513	509	472
80	1.15	433	509	472
90	1.54	380	509	472
100	1.94	340	509	472
110	2.33	300	509	472
120	2.72	300	509	472
130	3.12	253	509	472
140	3.51	253	509	472
150	3.91	253	509	472
160	4.30	220	509	472
170	4.69	220	509	472
180	5.09	220	509	472
⇩	⇩	⇩	⇩	⇩
590	21.23	220	509	472
600	21.62	220	509	472
610	22.02	220	509	472

Total 26,441 lb.

- In this case there were 56 segments at 10 mm per segment for a total embedment of 560 mm or 22.02 in.
- The accumulated bond strength from each segment totaled 26,441 lb. which > $f_y \cdot A_{se,N}$ = 26,400 lb.
- $\ell_{d,fire} = \ell_d$ = 22-inch
- As a shortcut, since the value of $\tau_{fire(\theta)}$ = 690 psi in the warmest section of the concrete (where c_b = 50mm in Step 3) is greater than τ_{equiv} = 509 psi, it could have already been determined that the ambient temperature development length controlled in lieu of the iterative calculation.

2.7 USE OF HILTI PROFIS SOFTWARE

The determination of the temperature in the concrete member can be very difficult, especially in cases where the temperature is variable over the bond length of the adhesive. This occurs when the geometry of the connection is occurring in beams and columns, instead of just walls and slabs, and when the fire exposure is on more than one face of the concrete. The temperature curves from ACI 216.1 are very basic and only consider fire exposure from one face of the concrete. As part of the Hilti Profis Engineering Suite, the Concrete-to-Concrete module has been updated to include fire design provisions. The calculations will be possible for many different configurations including slab-to-slab, slab-to-wall, etc. Finite element modeling is used which considers the geometry, the fire exposure from many different faces, and considers the mass of the concrete and steel reinforcing to distribute temperature

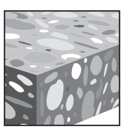
As such, there may be differences in the temperature determination between a hand calculation with ACI 216.1 figures and the Profis software. Contact Hilti for questions or for a demonstration on this innovation.

3.0 HILTI HIT-FP 700 R INJECTABLE CEMENTITIOUS MORTAR

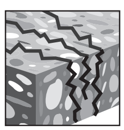
PRODUCT DESCRIPTION

HIT-FP 700 R adhesive with Rebar for development length calculations

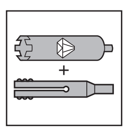
Anchor System		Features and Benefits
	Foil pack: HIT-FP 700 R (Available in 16.5 oz. / 490 ml cartridges)	• SafeSet™ technology: Simplified method of drilled hole preparation using either Hilti hollow drill bit for hammer drilling or roughening tool for diamond cored applications • OSHA Table 1926.1153 Table 1 compliant installation when installed with Hilti vacuum and DRS system or Hilti SafeSet™ hollow drill bit technology • High resistance to heat from elevated concrete temperatures when exposed to fire
	Rebar	• Suitable for real jobsite conditions — including water saturated concrete • Non-corrosive to rebar elements



Uncracked concrete



Cracked concrete



Diamond core drilling permitted only with Hilti Roughening Tool (RT)

Hollow drill bit

Fire resistance

Profis anchor design software (pending)

Approvals/Listings	
European technical assessment	ETA-21/0624 / 2022-06-17, CSTB, Mame la Vallée
NSF/ANSI Std 61	Certification for use in potable water

INSTALLATION PARAMETERS

Figure 3 — Hilti HIT-FP 700 R installation conditions

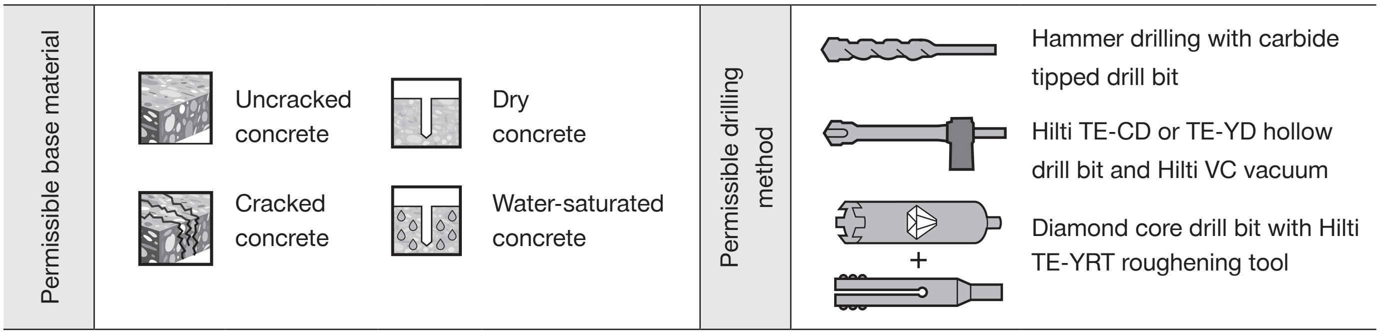


Figure 4 — Rebar installed with Hilti HIT-FP 700 R adhesive

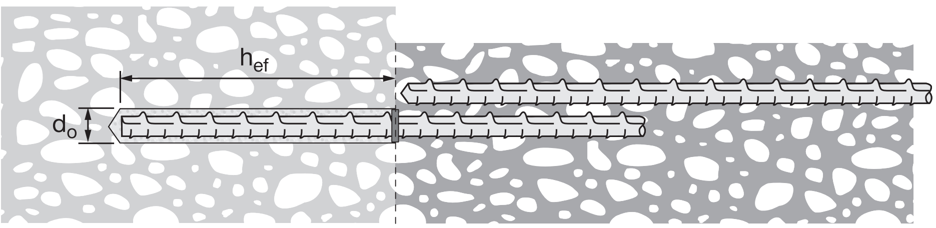


Table 1 — Specifications for ASTM A615/A706 rebar installed with HIT-FP 700 R adhesive[1]

Setting information		Symbol	Units	Rebar size											
				#3	#4	#5	#6	#6	#7	#7	#8	#8	#9	#10	#11
Nominal bit diameter		d_o	in.	1/2	5/8	3/4	7/8	1	1	1-1/8	1-1/8	1-1/4	1-3/8	1-1/2	1-3/4
Effective embedment	Minimum	$h_{ef,min}$	in.	2-3/8	2-3/4	3-1/8	3-1/2	15	3-1/2	17-1/2	4	20	4-1/2	5	5-1/2
			(mm)	(60)	(70)	(79)	(89)	(381)	(89)	(445)	(102)	(508)	(114)	(127)	(140)
	Maximum[2]	$h_{ef,max}$	in.	22-1/2	30	37-1/2	15	45	17-1/2	52-1/2	20	60	67-1/2	75	82-1/2
			(mm)	(572)	(762)	(953)	(381)	(1143)	(445)	(1334)	(508)	(1524)	(1715)	(1905)	(2096)
Minimum concrete member thickness		h_{min}	in.	h_{ef} + 1-1/4		$(h_{ef} + 2d_o)$									
			(mm)	$(h_{ef} + 30)$											

1 HIT-FP 700 R adhesive can be used with any grade of ASTM A615/A706 rebar.
2 Maximum effective embedment depth shown in table is $60d_b$ and can be increased as needed to satisfy calculated rebar development length for ambient temperature or fire condition.

Table 2 — Specifications for CSA-G30.18 rebar installed with HIT-FP 700 R adhesive[1]

Setting information		Symbol	Units	Rebar size				
				10M	15M	20M	25M	30M
Nominal bit diameter		d_o	in.	9/16	3/4	1	1-1/4	1-1/2
Effective embedment	Minimum	$h_{ef,min}$	mm	70	80	90	101	120
	Maximum[2]	$h_{ef,max}$	mm	678	960	1170	1512	1794
Minimum concrete member thickness		h_{min}	mm	$h_{ef} + 30$	$h_{ef} + 2d_o$			

1 HIT-FP 700 R adhesive can be used with any grade of CSA-G30.18 rebar.
2 Maximum effective embedment depth shown in table is $60d_b$ and can be increased as needed to satisfy calculated rebar development length for ambient temperature or fire condition.

POST-INSTALLED REBAR DESIGN FOR DEVELOPMENT LENGTH AMBIENT TEMPERATURE

The following tables show calculated development lengths per ACI 318 Chapter 25 or CSA A23.3 Chapter 12 for applications not considering fire exposure (ambient temperature). Refer to the Hilti North American Product Technical Guide: Post-Installed Reinforcing Bar Guide, dated November 2022 (Rebar Tech Guide), for more information on rebar development for post-installed rebar.

For rebar development considering fire exposure, the development length may need to be increased based on the temperature in the concrete for the specified rebar cover and fire duration. Refer to Figure 5 of this section and Section 2 of this document to determine the development length needed for the fire exposure condition.

Table 3 — Calculated tension development and Class B Splice development lengths for ASTM A615/A706 rebar in walls, slabs, columns, and footings per ACI 318 Chapter 25 for Hilti HIT-FP 700 R, not considering fire exposure [4,5,6]

Rebar size	$\frac{c_b + K_{tr}}{d_b}$	Min. edge dist. in.[1]	Min. spacing in.[2]	Concrete compressive strength $f'_c \geq$ 2,500 psi [3]			
				Gr. 40 rebar		Gr. 60 rebar	
				ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.
#3	2.5	2-1/4	2	12	12	12	14
#4		2-3/4	2-1/2	12	12	14	19
#5		3	3-1/4	12	16	18	23
#6		3-3/4	3-3/4	14	19	22	28
#7		4-1/2	4-1/2	21	27	32	41
#8		5	5	24	31	36	47
#9		5-1/4	5-3/4	27	35	41	53
#10		5-3/4	6-1/2	30	40	46	59
#11		6-1/2	7-1/4	34	44	51	66

1 Edge distance is determined using the minimum cover specified by ACI 318 Ch. 25 with an additional 6% of the development length per suggestions for drilling without an aid per Hilti Rebar Tech Guide Section 3.3. Smaller edge distances may be possible, for which development and splice lengths may need to be recalculated. For further information on required cover see ACI 318, Sec. 20.5.1.3.1.
2 Spacing values represent those producing c_b =5 d_b rounded up to the nearest 1/4 in. Smaller spacing values may be possible, for which development and splice lengths may need to be recalculated. For further information on required spacing see ACI 318 Sec. 25.2.
3 The development length is the same for all concrete compressive strengths as it is not permitted to increase the capacity value of f'_c used in the development length equations beyond 2,500 psi.
4 ψ_t = 1.0; ψ_e = 1.0 for non-epoxy coated bars; ψ_s = 0.8 for #6 bars and smaller bars, 1.0 for #7 and larger bars; ψ_g = 1.0, See ACI 318, Sec. 25.4.2.4.
5 Values are for normal weight concrete. For sand-lightweight concrete, multiply development and splice lengths by 1.18, for all-lightweight concrete multiply development and splice lengths by 1.33. See ACI 318 Sec. 19.2.4.
6 Development and splice length values are for static design. Seismic design not applicable for HIT-FP 700-R.

Table 4 — Calculated tension development and Class B Splice development lengths for CSA-G30.18 rebar in walls, slabs, columns, and footings per CSA A23.3 Clause 12 for Hilti HIT-FP 700 R, not considering fire exposure [4,5,6]

Rebar size	$d_{cs} + K_{tr}$	Min. edge dist. mm[1]	Min. spacing mm[2]	Concrete compressive strength $f'_c \geq$ 20 MPa [3]	
				Gr. 400 MPa	
				ℓ_d mm	Class B splice mm
10M	2.5 d_b	60	50	300	380
15M		70	75	410	540
20M		80	100	510	660
25M		120	125	820	1060
30M		130	150	960	1250

1 Edge distances are determined using the minimum cover specified by CSA A23.3 with an additional 6% of the development length per suggestions for drilling without an aid per Hilti Rebar Tech Guide Section 3.3. Smaller edge distances may be possible, for which development and splice lengths may need to be recalculated. For further information on required cover see CSA A23.3 Table 17.
2 Spacing values represent those producing d_{cs} =5 d_b rounded up to the nearest 10mm. Smaller spacing values may be possible, for which development and splice lengths may need to be recalculated. For further information on required spacing see CSA A23.3 Sec. 6.6.5.2.
3 The development length is the same for all concrete compressive strengths as it is not permitted to increase the capacity value of f'_c used in the development length equations beyond 20 MPa.
4 k_1 = 1.0; k_2 = 1.0 for uncoated reinforcement; k_3 = 1.0 for normal density concrete; k_4 = 0.8 for 20M bars and smaller bars, 1.0 for 25M and larger bars; See CSA A23.3 Clause 12.2.4.
5 Values are for normal weight concrete. For lightweight concrete, multiply development and splice lengths by 1.3.
6 Development and splice length values are for static design. Seismic design not applicable for HIT-FP 700-R.

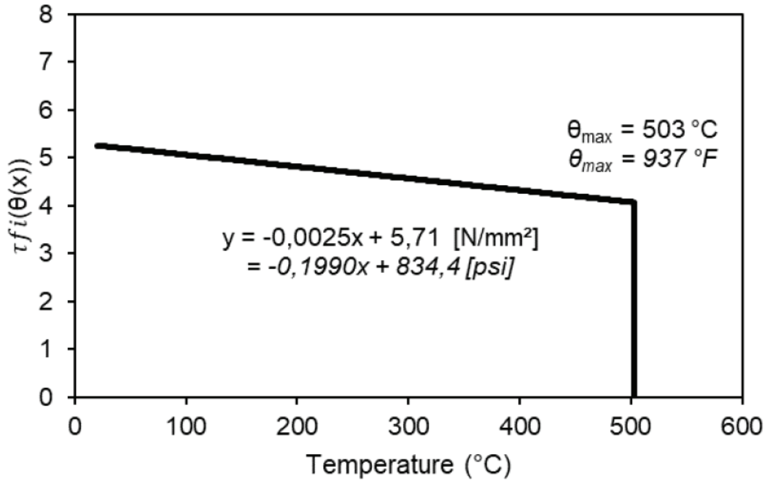
POST-INSTALLED REBAR DESIGN FOR DEVELOPMENT LENGTH FIRE EXPOSURE

Figure 5 below shows the effects of temperature on the HIT-FP 700R adhesive when exposed to a fire condition when used for development of rebar for either ACI or CSA code provisions. After determining the equivalent bond stress for the ambient temperature, τ_{equiv}, as noted in Section 2.1 of this document, then calculate the bond stress in the fire exposure condition, $\tau_{fire(\theta)}$ using the equations from Figure 5. The development length in the fire exposure condition, $\ell_{d,fire}$, will then be as follows:

$$\ell_{d,fire} = \frac{\tau_{equiv}}{\tau_{fire(\theta)}} \cdot \ell_d$$

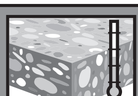
The final development length used would be the maximum of ℓ_d, or $\ell_{d,fire}$. See Section 2 of this document for more information on the design in fire exposure conditions.

Figure 5 — Hilti HIT-FP 700 R bond stress vs. temperature of post-installed rebar applications, short term loads and sustained loads, not-including seismic

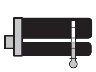


HIT-FP 700 R STANDARD CURE TIME

Figure 6 — Hilti HIT-FP 700 R standard adhesive cure and working time (approximate)



ø [°C]	ø [°F]	t_{work}	$t_{assembly}$	t_{cure}
5 ... 10	41 ... 50	50 min	36 h	28 days
11 ... 15	51 ... 59	40 min	30 h	21 days
16 ... 20	60 ... 68	35 min	24 h	17 days
21 ... 30	69 ... 86	20 min	12 h	7 days
31 ... 39	87 ... 103	15 min	6 h	5 days
40	104	12 min	3 h	4 days


≥ +5 °C / 41 °F

Where:

- t_{work} is the time after installation that the bar should not be tampered with.
- $t_{assembly}$ is the time after installation that it is permitted to begin to assemble formwork, tie rebar or pour concrete. (Concrete must be braced or shored until t_{cure} is reached).
- t_{cure} is the time when the adhesive has fully cured and is rated for in-service loads.

HIT-FP 700 R REDUCED CURE TIME

Figure 6 is intended for the full cure time of the product for in-service loads, including long-term loading. It may be desired to use a shorter cure time for conditions where the full in-service load is not being applied (i.e. temporary loads during construction). For example, if shoring is removed and the resulting load consists of short-term construction loads that are less than the in-service loads this may be possible.

Additional testing has been conducted on HIT-FP 700 R at reduced cure times. Table 5 provides reduction factors that can be applied at 2 and 3 days after installation at various temperature ranges, while Table 6 provides the number of days of t_{cure} at various temperatures that are needed for 75% of the full bond performance.

HIT-FP 700 R does not have published bond stresses, rather, it has been shown to be equivalent to a cast-in rebar, which does not use bond stress to calculate development length. To use the values in Table 5 or 6, determine the ratio of applied loads for the temporary load case (i.e. loads during construction) vs. the in-service loads ensuring that this ratio is less than the reduction factor, α, in Tables 5 or 6, based on the specific base material temperature for the project during the cure time.

Table 5 — Hilti HIT-FP 700 R temporary load reduction factor for reduced cure time, $t_{cure,reduced}$

Temperature (T)		α	
		2 days (48 hours)	3 days (72 hours)
5°C ≤ 10°C	41°F ≤ 50°F	0.35	0.39
11°C ≤ 15°C	51°F ≤ 59°F	0.46	0.54
16°C ≤ 20°C	60°F ≤ 68°F	0.53	0.60
21°C ≤ 30°C	69°F ≤ 86°F	0.60	0.69
31°C ≤ 39°C	87°F ≤ 103°F	0.64	0.75
40°C	104°F	0.75	0.87

Table 6 — Hilti HIT-FP 700 R reduced cure time, $t_{cure,reduced}$, for temporary load at 75% of in-service capacity

Temperature (T)		Reduced cure time, $t_{cure,reduced}$ for α ≥ 0.75
5°C ≤ 10°C	41°F ≤ 50°F	14 days
11°C ≤ 15°C	51°F ≤ 59°F	7 days
16°C ≤ 20°C	60°F ≤ 68°F	6 days
21°C ≤ 30°C	69°F ≤ 86°F	5 days
31°C ≤ 39°C	87°F ≤ 103°F	3 days
40°C	104°F	2 days

PRODUCT PORTFOLIO

HIT-FP 700 R

Description	Package contents	Qty
HIT-FP 700 R single cartridge (490ml/16.5 oz.)	Includes (1) foil pack with (1) mixer and 3/8 filler tube per pack	1
HIT-FP 700 R 1 Master Carton (1MC) blk cartridge	Includes (1) master carton containing (20) foil packs with (1) mixer and 3/8 filler tube per pack	20
HIT-FP 700 R 2 Master Carton (2MC) blk cartridge	Includes (1) master carton containing (40) foil packs with (1) mixer and 3/8 filler tube per pack	40
HIT-FP 700 R 5 Master Carton (5MC) blk cartridge	Includes (1) master carton containing (100) foil packs with (1) mixer and 3/8 filler tube per pack	100
HIT-FP 700 R 1 MC HDE22 with 1 battery and charger	Includes (1) master carton containing (20) foil packs each with (1) mixer and 3/8 filler tube per pack and (1) HDE smart dispenser (1) charger and battery	20
HIT-FP 700 R 2 MC HDE22 with 1 battery and charger	Includes (1) master carton containing (40) foil packs each with (1) mixer and 3/8 filler tube per pack and (1) HDE smart dispenser (1) charger and battery	40
HIT-FP 700 R 5 MC HDE22 with 1 battery and charger	Includes (1) master carton containing (100) foil packs each with (1) mixer and 3/8 filler tube per pack and (1) HDE smart dispenser (1) charger and battery	100
HIT-FP 700 R 1 MC HDE12v with 1 battery and charger	Includes (1) master carton containing (20) foil packs each with (1) mixer and 3/8 filler tube per pack (1) 12v HDE dispenser and (1) charger and battery	20
HIT-FP 700 R 2 MC HDE12v with1 battery and charger	Includes (1) master carton containing (40) foil packs each with (1) mixer and 3/8 filler tube per pack (1) 12v HDE dispenser and (1) charger and battery	40
HIT-FP 700 R 5 MC HDE12v with 1 battery and charger	Includes (1) master carton containing (100) foil packs each with (1) mixer and 3/8 filler tube per pack (1) 12v HDE dispenser and (1) charger and battery	100

4.0 HIT-RE 500 V3 EPOXY ADHESIVE ANHORING SYSTEM

Published technical data for HIT-RE 500 V3 can be found in the Hilti North American Product Technical Guide Volume 2: Anchor fastening technical guide, Edition 22 (PTG Ed. 22) and in ICC Evaluation Services ESR-3814 or ELC-3814. Refer to these documents for the full information on installation, application range, design data, and product portfolio

PRODUCT DESCRIPTION

HIT-RE 500 V3 adhesive with Rebar for development length calculations

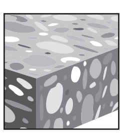
Anchor System

Hilti HIT-RE 500 V3 Cartridge

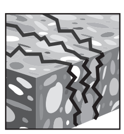
Rebar

Features and Benefits

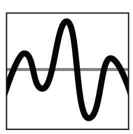
- Superior bond performance in both cracked and uncracked concrete
- Seismic qualified in accordance with ICC-ES Acceptance Criteria AC308 and AC 355.4
- No hole cleaning requirement when installed with Safe Set™ hollow drill bit and Hilti vacuum technology
- ICC-ES approved for cracked concrete and seismic service
- May be installed in diamond cored holes in cracked and uncracked concrete including all seismic zones concrete using the Safe-Set™ system using the TE-YRT Roughening tool
- Use underwater up to 165 ft (50 m)
- Meets requirements of AST C881-14, Type I, II, IV, and V, Grade 3, Class A, B, and C.
- Meets requirements of AASHTO specification M235, Type I, II, IV, and V, Grade 3, Class A, B, and C
- Technical data available for larger diameters, oversized holes, deeper embedments.
- Contact Hilti Technical Services for additional information



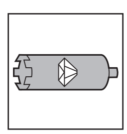
Uncracked concrete



Cracked concrete



Seismic design categories A-F



Diamond cored holes for cracked and uncracked concrete

Hollow drill bit Roughening tool

Profis anchor design software

Fire resistance

Approvals/Listings	
ICC-ES (International Code Council)	ESR-3814 in concrete per ACI 318 Ch. 17 / ACI 355.2/ ICC-ES AC308 ELC-3814 in concrete per CSA A23.3 / ACI 3552
NSF/ANSI Std 61	Certification for use in potable water
European Technical Approval	ETA-16/0142, ETA-16/0143, ETA-16/0180
City of Los Angeles	City of Los Angeles 2017 LABC Supplement (within ESR-3814)
Florida Building Code	2017 FB Supplement (within ESR-1814)
U.S. Green Building Council	LEED® Credit 4.1-Low Emitting Materials
Department of Transportation	Contact Hilt for various states

INSTALLATION PARAMETERS

Figure 7 — Hilti HIT-RE 500 V3 installation conditions

Cracked or uncracked concrete	Permissible drilling methods	Permissible concrete conditions
Uncracked Concrete Cracked concrete	Hammer drilling with carbide-tipped drill bit	Dry concrete; Water-saturated concrete; Water-filled holes; Submerged (underwater)
	Hilti TE-CD or TE-YD hollow drill bit and Hilti VC vacuum + Diamond core drill bit with Hilti TE-YRT roughening tool	Dry concrete; Water-saturated concrete
Uncracked concrete	Diamond core drill bit	Dry concrete; Water-saturated concrete

Figure 8 — Rebar installed with Hilti HIT-RE 500 V3 adhesive

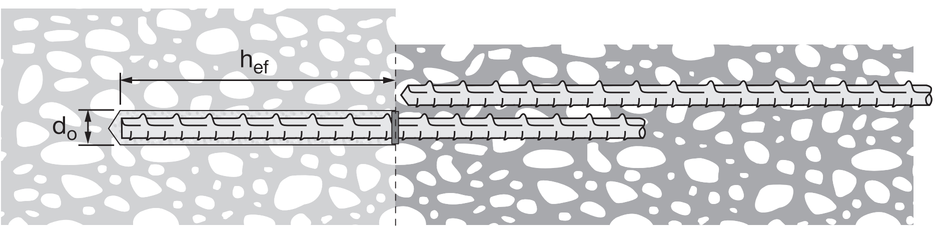


Table 7 — Specifications for ASTM A615/A706 rebar installed with HIT-RE 500 V3 adhesive [1]

Setting information		Symbol	Units	Rebar size											
				#3	#4	#5	#6	#6	#7	#7	#8	#8	#9	#10	#11
Nominal bit diameter		d_o	in.	1/2	5/8	3/4	7/8	1	1	1-1/8	1-1/8	1-1/4	1-3/8	1-1/2	1-3/4
Effective embedment	Minimum	$h_{ef,min}$	in. (mm)	2-3/8 (60)	2-3/4 (70)	3-1/8 (79)	3-1/2 (89)	15 (381)	3-1/2 (89)	17-1/2 (445)	4 (102)	20 (508)	4-1/2 (114)	5 (127)	5-1/2 (140)
	Maximum[2]	$h_{ef,max}$	in. (mm)	22-1/2 (572)	30 (762)	37-1/2 (953)	15 (381)	45 (1143)	17-1/2 (445)	52-1/2 (1334)	20 (508)	60 (1524)	67-1/2 (1715)	75 (1905)	82-1/2 (2096)
Minimum concrete member thickness		h_{min}	in. (mm)	h_{ef} + 1-1/4 (h_{ef} + 30)		$(h_{ef} + 2d_o)$									

1 HIT-RE 500 V3 adhesive can be used with any grade of ASTM A615/A706 rebar.
2 Maximum effective embedment depth shown in table is $60d_b$ and can be increased as needed to satisfy calculated rebar development length for ambient temperature or fire condition.

Table 8 — Specifications for CSA-G30.18 rebar installed with HIT-RE 500 V3 adhesive [1]

Setting information		Symbol	Units	Rebar size				
				10M	15M	20M	25M	30M
Nominal bit diameter		d_o	in.	9/16	3/4	1	1-1/4	1-1/2
Effective embedment	Minimum	$h_{ef,min}$	mm	70	80	90	101	120
	Maximum[2]	$h_{ef,max}$	mm	678	960	1170	1512	1794
Minimum concrete member thickness		h_{min}	mm	h_{ef} + 30	$h_{ef} + 2d_o$			

1 HIT-RE 500 V3 adhesive can be used with any grade of CSA-G30.18 rebar.
2 Maximum effective embedment depth shown in table is $60d_b$ and can be increased as needed to satisfy calculated rebar development length for ambient temperature or fire condition.

POST-INSTALLED REBAR DESIGN FOR DEVELOPMENT LENGTH AMBIENT TEMPERATURE

The following tables show calculated development lengths per ACI 318 Chapter 25 or CSA A23.3 Chapter 12 for applications not considering fire exposure (ambient temperature). Refer to the Hilti North American Product Technical Guide: Post-Installed Reinforcing Bar Guide, dated November 2022 (Rebar Tech Guide), for more information on rebar development for post-installed rebar.

For rebar development considering fire exposure, the development length may need to be increased based on the temperature in the concrete for the specified rebar cover and fire duration. Refer to Figures 9 and 10 of this section and Section 2 of this document to determine the development length needed for the fire exposure condition.

Table 9 — Calculated tension development and Class B Splice development lengths for ASTM A615 Grade 40 rebar in walls, slabs, columns, and footings per ACI 318 Chapter 25 for Hilti HIT-RE 500 V3, not considering fire exposure [3,4,5]

Rebar size	$\frac{c_b + K_{tr}}{d_b}$	Min. edge dist. in.[1]	Min. spacing in.[2]	f'_c = 2,500 psi		f'_c = 3,000 psi		f'_c = 4,000 psi		f'_c = 6,000 psi	
				ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.
#3	2.5	2-1/4	2	12	12	12	12	12	12	12	12
#4		2-3/4	2-1/2	12	12	12	12	12	12	12	12
#5		3	3-1/4	12	16	12	14	12	12	12	12
#6		3-3/4	3-3/4	14	19	13	17	12	15	12	12
#7		4-1/2	4-1/2	21	27	19	25	17	22	14	18
#8		5	5	24	31	22	28	19	25	15	20
#9		5-1/4	5-3/4	27	35	25	32	21	28	17	23
#10		5-3/4	6-1/2	30	40	28	36	24	31	20	26
#11		6-1/2	7-1/4	34	44	31	40	27	35	22	28

Table 10 — Calculated tension development and Class B Splice development lengths for ASTM A615/A706 Grade 60 rebar in walls, slabs, columns, and footings per ACI 318 Chapter 25 for Hilti HIT-RE 500 V3, not considering fire exposure [3,4,5]

Rebar size	$\frac{c_b + K_{tr}}{d_b}$	Min. edge dist. in.[1]	Min. spacing in.[2]	f'_c = 2,500 psi		f'_c = 3,000 psi		f'_c = 4,000 psi		f'_c = 6,000 psi	
				ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.	ℓ_d in.	Class B splice in.
#3	2.5	2-1/4	2	12	14	12	13	12	12	12	12
#4		2-3/4	2-1/2	14	19	13	17	12	15	12	12
#5		3	3-1/4	18	23	16	21	14	18	12	15
#6		3-3/4	3-3/4	22	28	20	26	17	22	14	18
#7		4-1/2	4-1/2	32	41	29	37	25	32	20	26
#8		5	5	36	47	33	43	28	37	23	30
#9		5-1/4	5-3/4	41	53	37	48	32	42	26	34
#10		5-3/4	6-1/2	46	59	42	54	36	47	30	38

Footnotes applicable to Tables 9 and 10:

1 Edge distance is determined using the minimum cover specified by ACI 318 Ch. 25 with an additional 6% of the development length per suggestions for drilling without an aid per Hilti Rebar Tech Guide Section 3.3. Smaller edge distances may be possible, for which development and splice lengths may need to be recalculated. For further information on required cover see ACI 318, Sec. 20.5.1.3.1.

2 Spacing values represent those producing c_b =5 d_b rounded up to the nearest 1/4 in. Smaller spacing values may be possible, for which development and splice lengths may need to be recalculated. For further information on required spacing see ACI 318 Sec. 25.2.

3 ψ_t = 1.0; ψ_e = 1.0 for non-epoxy coated bars; ψ_s = 0.8 for #6 bars and smaller bars, 1.0 for #7 and larger bars; ψ_g = 1.0, See ACI 318, Sec. 25.4.2.4.

4 Values are for normal weight concrete. For sand-lightweight concrete, multiply development and splice lengths by 1.18, for all-lightweight concrete multiply development and splice lengths by 1.33. See ACI 318 Sec. 19.2.4.

5 Development and splice length values are for static design. Seismic design development and splice lengths can be found in ACI 318 18.8.5 for special moment frames and ACI 318 18.10.2.3 for special structural walls. For further information about reinforcement in seismic design, see ACI 318 Ch. 18.

Table 11 — Calculated tension development and Class B Splice development lengths for CSA-G30.18 rebar in walls, slabs, columns, and footings per CSA A23.3 Clause 12 for Hilti HIT-RE 500 V3, not considering fire [3,4,5]

Rebar size	$d_{cs} + K_{tr}$	min. edge dist. mm[1]	min. spacing mm[2]	f'_c = 20 MPa		f'_c = 25 MPa		f'_c = 30 MPa		f'_c = 40 MPa	
				ℓ_d mm	Class B splice mm	ℓ_d mm	Class B splice mm	ℓ_d mm	Class B splice mm	ℓ_d mm	Class B splice mm
10M	2.5 d_b	60	50	300	380	300	340	300	310	300	300
15M		70	75	410	540	370	480	340	440	300	380
20M		80	100	510	660	450	490	410	540	360	460
25M		120	125	820	1,060	730	950	670	870	580	750
30M		130	150	960	1,250	860	1,120	790	1,020	680	890

1 Edge distances are determined using the minimum cover specified by CSA A23.3 with an additional 6% of the development length per suggestions for drilling without an aid per Hilti Rebar Tech Guide Section 3.3. Smaller edge distances may be possible, for which development and splice lengths may need to be recalculated. For further information on required cover see CSA A23.3 Table 17.
2 Spacing values represent those producing d_{cs} =5 d_b rounded up to the nearest 10mm. Smaller spacing values may be possible, for which development and splice lengths may need to be recalculated. For further information on required spacing see CSA A23.3 Sec. 6.6.5.2.
3 k_1 = 1.0; k_2 = 1.0 for uncoated reinforcement; k_3 = 1.0 for normal density concrete; k_4 = 0.8 for 20M bars and smaller bars, 1.0 for 25M and larger bars; See CSA A23.3 Clause 12.2.4.
4 Values are for normal weight concrete. For lightweight concrete, multiply development and splice lengths by 1.3.
5 Development and splice length values are for static design. For tension development and splice lengths of bars in joints, see CSA A23.3 21.3.3.5. For further information about reinforcement in seismic design, see CSA A23.3 Ch. 21.

POST-INSTALLED REBAR DESIGN FOR DEVELOPMENT LENGTH FIRE EXPOSURE

Figures 9 and 10 below are from ESR-3814 and shows the effects of temperature on the HIT-RE 500 V3 adhesive when exposed to a fire condition when used for development of rebar for either ACI or CSA code provisions. After determining the equivalent bond stress for the ambient temperature, τ_{equiv}, as noted in Section 2.1 of this document, then calculate the bond stress in the fire exposure condition, $\tau_{fire(\theta)}$ using the equations from Figures 9 and 10. The development length in the fire exposure condition, $\ell_{d,fire}$, will then be as follows:

$$\ell_{d,fire} = \frac{\tau_{equiv}}{\tau_{fire(\theta)}} \cdot \ell_d$$

The final development length used would be the maximum of ℓ_d, or $\ell_{d,fire}$. See Section 2 of this document for more information on the design in fire exposure conditions.

Figure 9 — HIT-RE 500 V3 bond stress vs. temperature of post-installed rebar applications, short term loads including seismic

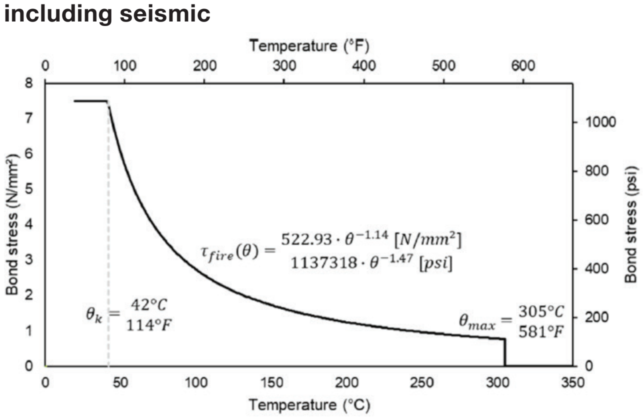
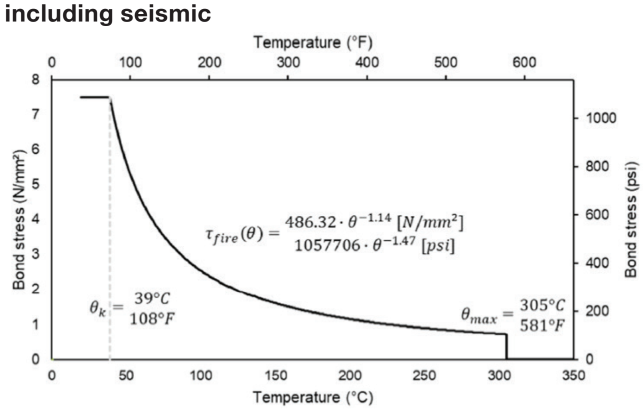


Figure 10 — HIT-RE 500 V3 bond stress vs. temperature of post-installed rebar applications, sustained loads including seismic



Hilti, Inc.
1-800-879-8000 | en español 1-800-879-5000
www.hilti.com

Hilti (Canada) Corporation
1-800-363-4458
www.hilti.ca

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