# 1-DAY SEMINAR
# ON
# "PERFORMANCE EVALUATION FOR CONCRETE TO CONCRETE CONNECTION: FROM QUALIFICATION TO DESIGN"

**SPEAKERS:**

Dr. Daniel LOOI Ting Wee (Swinburne University of Technology, Sarawak)
Ir. NG Beng Hooi (Hilti Malaysia)
Ir. MUN Yew Fai (Hilti Malaysia)

## CONTENTS

# OVERVIEW OF POST INSTALLED REBAR TECHNOLOGY IN MALAYSIA

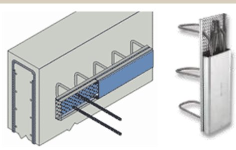
Ir Ng Beng Hooi
24th September 2018

## POST-INSTALLING REBAR METHOD FOR CONCRETE CONNECTION

**Mechanical couplers**

- + Very attractive method for pre-fabricated slabs
- − Risk of misplacement
- − Localised reduction of the bars cross-section
- − Limited to new projects

**Pre-cast rebar sets**



- + Relatively easy to install and straighten the bars
- − Risk of misplacement
- − Typically expensive solution
- − Limited to smaller bars
- − Limited to new projects

**Perforated formwork**

- + Positioning of the bars mostly guaranteed
- − Holes in formwork neutralizes reutilisation
- − Leakage of cement reduces concrete quality in the connection
- − Limited to new projects

# POST-INSTALLING REBAR METHOD FOR CONCRETE CONNECTION

### Chiseling, Welding

- \+ Load transferred directly to the existing bars
- – Risk of creating concrete cracks along the bars
- – High dependency of the quality of the welding
- – Welding can't be done in unfavourable weather

### Cementitious grouts

- \+ Low cost of grout per ml.
- – Can only be installed downwards or inclined
- – Dubious control over the mixture done on jobsite
- – Typical large drilling diameter vs bar size

### Adhesive mortars

- \+ Mixture quality ensured by dispenser units
- \+ Small sized diameter and high bond strength
- – Drilling required
- – Higher cost of mortar per ml.

# REBAR APPLICATIONS CAN BE CLASSIFIED INTO THREE MAIN CATEGORIES

### Lap Splices / Splicing

### Structural Joints

### Overlays

## THESE ARE EXAMPLES OF REBAR APPLICATIONS, WHICH HAVE THE OBJECTIVE OF CONNECTING MEMBERS

**Slab to Diaphragm Wall** (slab to wall)

**New Slab/ Renovation** (slab to wall)

**New Wall** (wall to slab/ foundation)

**Balcony Extension** (slab to slab)

**Upstands**

**Wall tie connection**

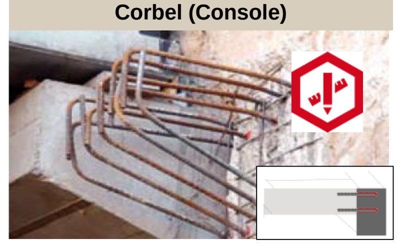
7

## THESE ARE EXAMPLES OF REBAR APPLICATIONS, WHICH HAVE THE OBJECTIVE OF CONNECTING MEMBERS

**New Column/ Column extension**

**Beam extension**

**Corbel (Console)**



**Close Opening (wall, slab, etc.)**

**Strutting/ELS support with rebar**

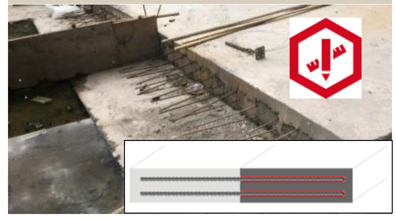
**Bridge Extension** (slab to wall/slab)

## THESE ARE EXAMPLES OF REBAR APPLICATIONS, WHICH HAVE THE OBJECTIVE OF CONNECTING MEMBERS

**Office Building Staircases**

**Residential Staircases**

**Floor extension**



**Wall Extension** (wall to wall)

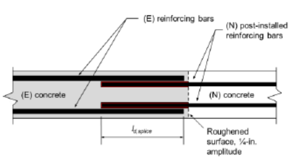
**Safety Barriers**

**Slab to CBP Wall**

## FROM POST-INSTALLED REBAR TO CONCRETE TO CONCRETE CONNECTION APPLICATIONS

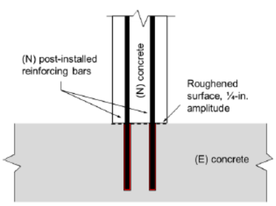
**Splices**

(wall/ slab/ column/ beam extensions)



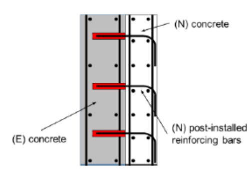

**Structural Joints**

(beam-column, column-foundation, wall-slab, stairs, etc.)




**Shear friction applications**

(wall/ slab widening, etc.)




# WE ALWAYS DESIGN ONLY REFER TO LOADING TABLE??

Rebar $f_{yk}$ 500 N/mm²
Class of Concrete 40 N/mm²

| Bar Size (mm) | T10 | T13 | T16 | T20 | T25 | T32 | T40 |
|---|---|---|---|---|---|---|---|
| Drill Bit Diameter (mm) | 13-14 | 16-18 | 20-22 | 25-28 | 30-32 | 40-42 | 50-52 |
| Cross Section (mm²) | 78.60 | 132.70 | 201.10 | 314.20 | 490.00 | 804.4 | 1256.80 |
| Spacing (mm) | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Cold Design, Embedment (mm) | 125.00 | 160.00 | 200.00 | 263.00 | 332.00 | 497.00 | 652.00 |
| Yield Strength (KN) | 34.19 | 57.72 | 87.48 | 136.68 | 213.15 | 349.91 | 546.71 |
| Hot Design, Embedment (mm) | 325.00 | 350.00 | 405.00 | 460.00 | 520.00 | 610.00 | 710.00 |
| Tensile Strength (KN) | 25.30 | 36.40 | 64.80 | 101.20 | 158.10 | 259.00 | 404.70 |

Product:
Rebar Strength 460 N/mm² Min. Edge 40.0 mm
Concrete Class 37 N/mm² Min. Spacing 5.0 ø c/c

Safety Factors
Steel $\gamma_s$ 1.15
Bond $\gamma_b$ 1.8
Concrete $\gamma_c$ 1.5

| Bar Size | ø | mm | 10 | 13 | 16 | 20 | 25 | 28 | 32 | 40 | $N^{o}_{Rdc}$ - Design Concrete Resistance (KN) - 3) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drilled Hole (mm) | $D_o$ | mm | 13 | 16 | 20 | 25 | 30 | 35 | 40 | 50 | |
| Bar Area Cross-Section | $A_s$ | mm² | 78.6 | 132.7 | 201.1 | 314.2 | 490.9 | 615.8 | 804.3 | 1256.8 | |
| Steel Design Yield - 1) 87% Yield Strength | | KN | 31.4 | 53.1 | 80.4 | 125.7 | 196.4 | 246.3 | 321.7 | 502.7 | |
| Design Bond Strength | $f_b$ | N/mm² | 7.77 | 7.22 | 6.66 | 6.66 | 6.11 | 6.11 | 6.11 | 6.11 | |
| Min. Bar to Edge - (30mm + 0.06 $l_s$) | $C_{min}$ (Whichever Higher) Min. 40mm | mm | 38 | 41 | 44 | 48 | 54 | 57 | 60 | 68 | |
| Min. Spacing >5ds (c/c) | $S_{min}$ (Whichever Higher) Min. 40mm | mm | 50 | 65 | 80 | 100 | 125 | 140 | 160 | 200 | |
| Basic Embedment depth to achieved 87% of Design Steel Yield | | mm | 125 | 175 | 235 | 295 | 395 | 445 | 505 | 630 | |
| Design Tensile Bond Resistance (KN) for Non Cracked Concrete - 2) / Anchorage Length [mm] | 90 | mm | 22.9 | 27.6 | 31.3 | 39.2 | 44.9 | 50.3 | 57.5 | 71.9 | 35.0 |
| | 100 | mm | 25.4 | 30.7 | 34.8 | 43.5 | 49.9 | 55.9 | 63.9 | 79.9 | 41.0 |
| | 110 | mm | 27.9 | 33.7 | 38.3 | 47.9 | 54.9 | 61.5 | 70.3 | 87.8 | 47.3 |
| | 120 | mm | 30.5 | 36.8 | 41.8 | 52.2 | 59.9 | 67.1 | 76.7 | 95.8 | 53.8 |
| | 125 | mm | 31.4 | 38.3 | 43.5 | 54.4 | 62.4 | 69.9 | 79.9 | 99.8 | 57.2 |
| | 150 | mm | | 46.0 | 52.2 | 65.3 | 74.9 | 83.9 | 95.8 | 119.8 | 75.2 |
| | 160 | mm | | 49.1 | 55.7 | 69.6 | 79.9 | 89.4 | 102.2 | 127.8 | 82.9 |
| | 175 | mm | | 53.1 | 60.9 | 76.2 | 87.3 | 97.8 | 111.8 | 139.8 | 94.8 |
| | 200 | mm | | | 69.6 | 87.1 | 99.8 | 111.8 | 127.8 | 159.7 | 115.8 |
| | 220 | mm | | | 76.6 | 95.8 | 109.8 | 123.0 | 140.6 | 175.7 | 133.6 |
| | 230 | mm | | | 80.1 | 100.1 | 114.8 | 128.6 | 146.9 | 183.7 | 142.9 |
| | 235 | mm | | | 80.4 | 102.3 | 117.3 | 131.4 | 150.1 | 187.7 | 147.5 |
| | 240 | mm | | | | 104.5 | 119.8 | 134.2 | 153.3 | 191.7 | 152.3 |
| | 260 | mm | | | | 113.2 | 129.8 | 145.3 | 166.1 | 207.6 | 171.7 |
| | 280 | mm | | | | 121.9 | 139.8 | 156.5 | 178.9 | 223.6 | 191.9 |
| | 295 | mm | | | | 125.7 | 147.2 | 164.9 | 188.5 | 235.6 | 207.5 |
| | 330 | mm | | | | | 164.7 | 184.5 | 210.8 | 263.5 | 245.5 |
| | 350 | mm | | | | | 174.7 | 195.7 | 223.6 | 279.5 | 268.2 |
| | 380 | mm | | | | | 189.7 | 212.4 | 242.8 | 303.5 | 303.4 |
| | 395 | mm | | | | | 196.4 | 220.8 | 252.4 | 315.5 | 321.5 |
| | 400 | mm | | | | | | 223.6 | 255.6 | 319.4 | 327.7 |
| | 420 | | | | | | | 234.8 | 268.3 | 335.4 | 352.5 |
| | 440 | mm | | | | | | 246.0 | 281.1 | 351.4 | 378.0 |
| | 445 | mm | | | | | | 246.3 | 284.3 | 355.4 | 384.5 |
| | 450 | mm | | | | | | | 287.5 | 359.4 | 391.0 |
| | 460 | mm | | | | | | | 293.9 | 367.4 | 404.1 |
| | 480 | mm | | | | | | | 306.7 | 383.3 | 430.7 |
| | 505 | mm | | | | | | | 321.7 | 403.3 | 464.8 |
| | 520 | mm | | | | | | | | 415.3 | 485.7 |
| | 530 | mm | | | | | | | | 423.3 | 499.7 |
| | 580 | mm | | | | | | | | 463.2 | 572.1 |
| | 630 | mm | | | | | | | | 502.7 | 647.7 |

Design pullout loads acc. to rebar theory depending on the anchorage length in C20/25 non-cracked concrete

| Rebar, $f_{yk}$ 460 N/mm² | $d_s$ | mm | Ø8 | Ø10 | Ø13 | Ø16 | Ø20 | Ø25 | Ø28 | Ø32 | Ø40 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Drill bit/ hole diameter | $d_0$ | mm | 12 | 14 | 16 | 20 | 25 | 32 | 35 | 40 | 50 |
| Bar Cross-Section Area | $A_s$ | mm² | 50.3 | 78.5 | 132.7 | 201.1 | 314.2 | 490.9 | 615.8 | 804.2 | 1257 |
| Design Rebar Yield | $N_{yd,s}$ | kN | 20.1 | 31.4 | 53.1 | 80.4 | 125.7 | 196.3 | 246.3 | 321.7 | 502.7 |
| Design Bond Strength | $f_{bd}$ | N/mm² | 7.7 | 7.7 | 7.2 | 6.7 | 6.7 | 6.1 | 6.1 | 6.1 | 4.8 |
| Edge Distance | c | mm | edge distance (concrete cover) according to EC2 design | | | | | | | | |
| Spacing Distance | s | mm | spacing distance according to EC2 design | | | | | | | | |
| Design Tensile Loads (kN) / Anchorage Length, $l_b$ | 90 | mm | 17.4 | 21.8 | | | | | | | |
| | 100 | mm | 19.4 | 24.2 | 29.4 | | | | | | |
| | 105 | mm | 20.3 | 25.4 | 30.9 | | | | | | |
| | 120 | mm | | 29.0 | 35.3 | 40.4 | | | | | |
| | 130 | mm | | 31.5 | 38.2 | 43.8 | 54.7 | | | | |
| | 160 | mm | | | 47.1 | 53.9 | 67.4 | 76.7 | | | |
| | 182 | mm | | | 53.5 | 61.3 | 76.6 | 87.2 | | | |
| | 200 | mm | | | | 67.4 | 84.2 | 95.8 | 107.3 | | |
| | 240 | mm | | | | 80.8 | 101.0 | 115.0 | 128.8 | | |
| | 250 | mm | | | | | 105.3 | 119.8 | 134.2 | 153.3 | |
| | 300 | mm | | | | | 126.3 | 143.7 | 161.0 | 184.0 | 181.0 |
| | 400 | mm | | | | | | 191.7 | 214.7 | 245.3 | 241.3 |
| | 410 | mm | | | | | | 196.5 | 220.0 | 251.5 | 247.3 |
| | 460 | mm | | | | | | | 246.9 | 282.1 | 277.5 |
| | 500 | mm | | | | | | | | 306.7 | 301.6 |
| | 525 | mm | | | | | | | | 322.0 | 316.7 |
| | 600 | mm | | | | | | | | | 362.0 |
| | 635 | mm | | | | | | | | | 503.7 |

The design only consider Bond Strength for the Epoxy!!!!
Is that Sufficient ???

# REBAR APPLICATIONS CONSIST OF SHEAR, TENSION, MOMENT OR COMBINED LOADING. HENCE, DIFFERENT APPLICATION REQUIRES DIFFERENT EMBEDMENT DEPTH.


Misaligned couplers


Slab to diaphragm wall


Slab to CBP wall


Slab Extension


Column Extension


Beam to Column


Pile cap


Skin wall

# REBAR APPLICATIONS CONSIST OF SHEAR, TENSION, MOMENT OR COMBINED LOADING. HENCE, DIFFERENT APPLICATION REQUIRES DIFFERENT EMBEDMENT DEPTH.


**Misaligned couplers**


**Slab to diaphragm wall**


**Slab to CBP wall**


**Slab Extension**

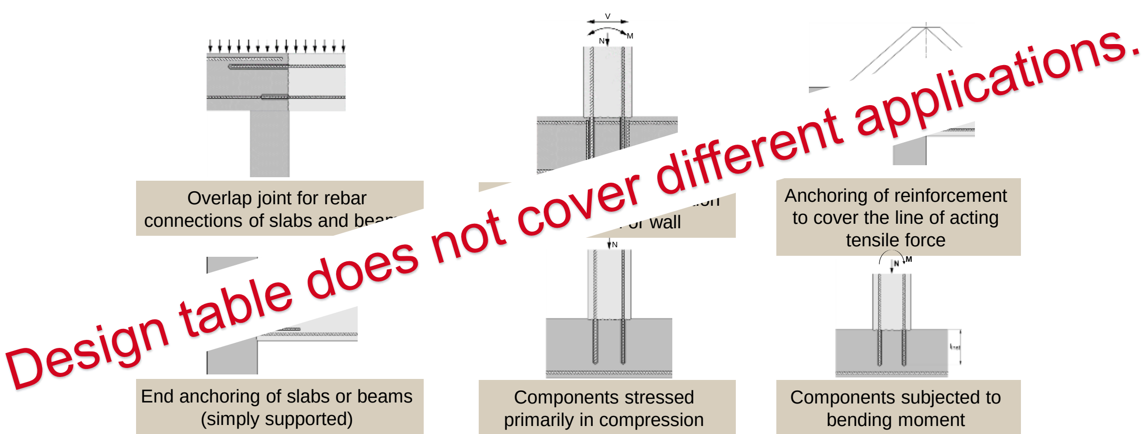

**Column Extension**


**Beam to Column**


**Pile cap**

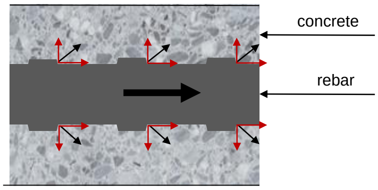

**Skin wall**

# A GENERIC REBAR DESIGN TABLE CANNOT BE USED FOR ALL REBAR APPLICATIONS



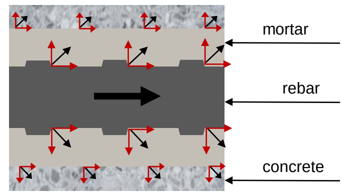
# DIFFRENCE LOAD-TRANSFER MECHANISM BETWEEN POST-INSTALLED AND CAST-IN REBARS

**Cast-in rebars**




Load is transferred by mechanical interlock provided by the ribs. The mechanical interlock leads to compression struts which lead to rotational tensile stresses perpendicular to the loading direction.

**Post-installed rebars**




At the mortar-concrete interface load is transferred by adhesion and micro-interlock due to roughness of the drilled hole surface. The stiffness of the mortar is responsible for the crack surface of the pull-out.

# DID WE DO PROPER DESIGN AND INSTALLATION FOR CONCRETE CONNECTIONS?


**Misaligned couplers**


**Slab to diaphragm wall**


**Slab to CBP wall**


**Slab Extension**


**Column Extension**


**Beam to Column**


**Pile cap**


**Skin wall**

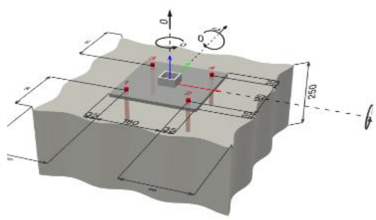
**Post-Installed rebar widely used in both structural and non-structural elements.**
**All of them are directly or in directly link to the safety of human being or economic investment**

## UNDERSTANDING THE APPLICATION NEEDS AND DOING A PROPER DESIGN IS THE FIRST STEP

**All different influencing factors must be considered in the design**

**Corrosion:**
In-Door, Out-Door, Sea Side or.....

**Loading condition**:
Static (cracked concrete), Seismic, Fire?



**Installation info:**
Geometry,
Temperature,
installation method

## CONSEQUENCE FOR NOT TREATING THEM SERIOUSLY

Installation problem, structure pull out from concrete
No proper design, anchor under design
Do not consider for long term strength, deformation and durability problem

## CONSEQUENCE FOR NOT TREATING THEM SERIOUSLY

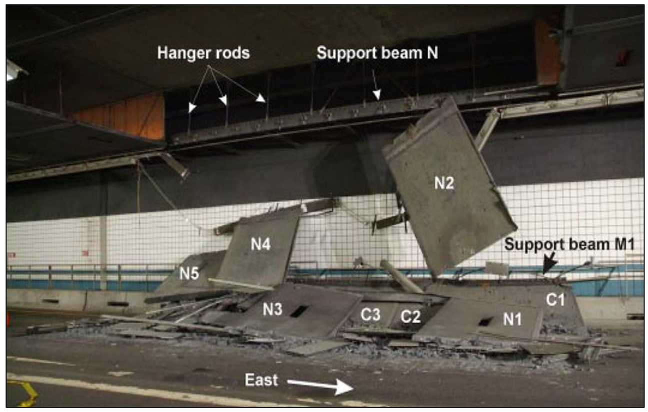

No proper design, Concrete Edge Failure
Brittle Concrete Failure. One example of failure on site due to embedment depth and spacing of post installed rebar.

## CONSEQUENCE FOR NOT TREATING THEM SERIOUSLY

Anchor pull out after heavy rain, Rainshelter Collapse

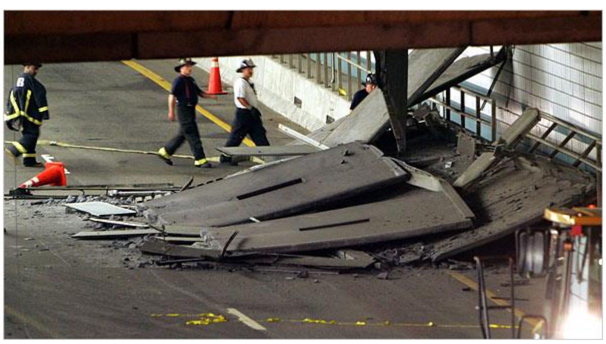
35 tonne panel that collapsed onto the crane during erection

## CONSEQUENCE FOR NOT TREATING THEM SERIOUSLY




Ceiling slab collapsed.
Improper Installation and sustained load are the main reason
**Collapse of suspended concrete ceiling, a vehicle was partially crushed, killing a passenger**

## ACCIDENTS HAVE SHOWN THAT FAILURE CAN HAPPEN AFTER YEARS OF INSTALLATION



— The ceiling collapsed in one of tunnels a year ago, killing one woman, because builders used the wrong epoxy to hold the anchor bolts in place, the National Transportation Safety Board said Tuesday.
“We’re talking about the wrong glue here, in effect,” said , one of the five members of the board, which said that the epoxy selected dried quickly but lost strength weeks later.

On July 10, 2007, after a lengthy investigation, the National Transportation Safety Board found that epoxy glue used to hold the roof in place during construction was not appropriate for long-term bonding.[59] This was determined to be the cause of the roof collapse.

## WHAT DIMENSION SHALL BE CHECKED?

IS THIS GOOD ENOUGH TO ENSURE OUR STRUCTURE CAN LAST FOR 50 YEARS OR 100 YEARS ???

| Ultimate limit state | Service limit state | …ability |
| --- | --- | --- |
|  |  |  |
| Fastener sh… load actions … ution and …se | Fastener shall not deform to an inadmissible degree | Fastener shall remain fit for use taking into account the environmental conditions for the structure. |

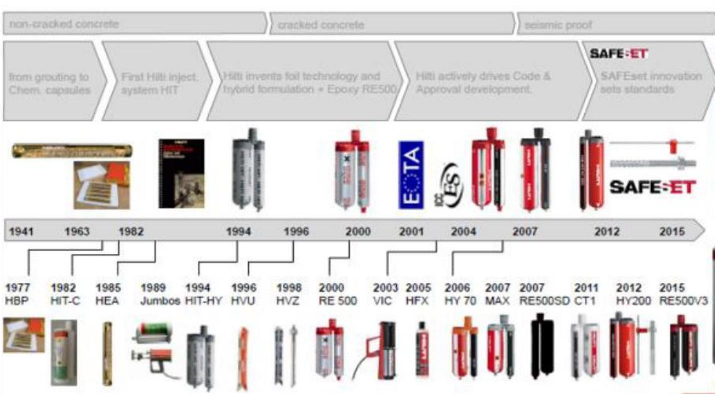
## …AND ACCIDENTAL EVENTS SHALL NOT BE OVERLOOKED

| Fire | Seismic |
| --- | --- |
|  |  |

**Anchor fasteners / Post-Installed Rebar have different behavior (load resistance and displacement) in these cases, a proper design has to be done accordingly!**

# POST INSTALLED REBAR TECHNOLOGY IN MALAYSIA……

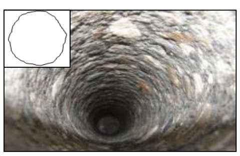
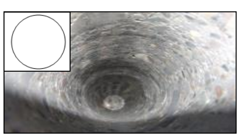
## MANY PRODUCTS IN MARKET AND THE TECHNOLOGY KEEP IMPROVE




## ANCHORS CAN BE OF MANY DIFFERENT TYPES BUT THE INSTALLATION PROCEDURE FOLLOWS THE SAME STEPS

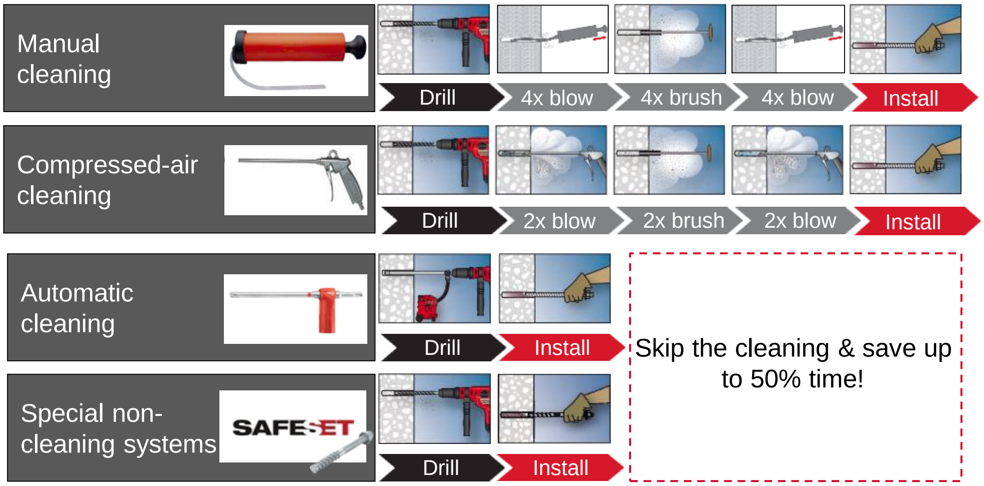
Positioning → Drilling → Cleaning → Setting → Loading


## DRILLING METHODS AND CLEANING WILL EFFECT THE PIR PERFORMANCE

| | | |
|---|---|---|
| Rotary drilling<br>sensitive material |  | Without percussion, for more sensitive material<br>(e.g. masonry) |
| Hammer drilling |  | Standard drill<br>Hollow drill bit<br>Special drills |
| Diamond drilling<br>• Cuts through rebar<br>• High precision<br>• Low vibration & noise<br> |  | Diamond drill<br>(reduced performance vs hammer drill) |
| |  | Diamond drill<br>+roughening tool<br>(equal performance vs hammer drill) |

# CLEANING METHODS FOR HAMMER DRILLING

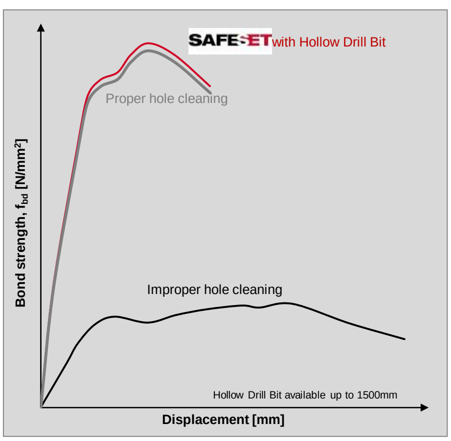
e.g. Hilti HIT-HY 200 chemical anchor system



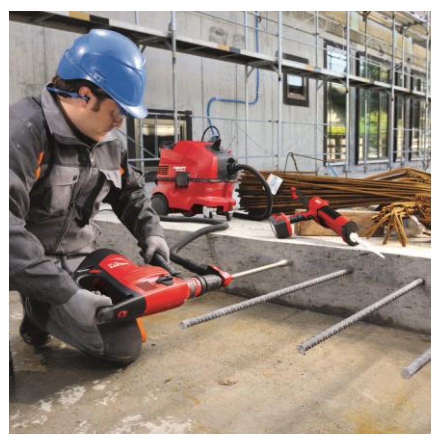
| | |
| --- | --- |
| Manual cleaning | Drill → 4x blow → 4x brush → 4x blow → Install |
| Compressed-air cleaning | Drill → 2x blow → 2x brush → 2x blow → Install |
| Automatic cleaning | Drill → Install |
| Special non-cleaning systems (SAFESET) | Drill → Install |

Skip the cleaning & save up to 50% time!

# SAFESET DRILLING GIVES YOU BETTER CLEANING PROCESS IN HAMMER DRILLED HOLES

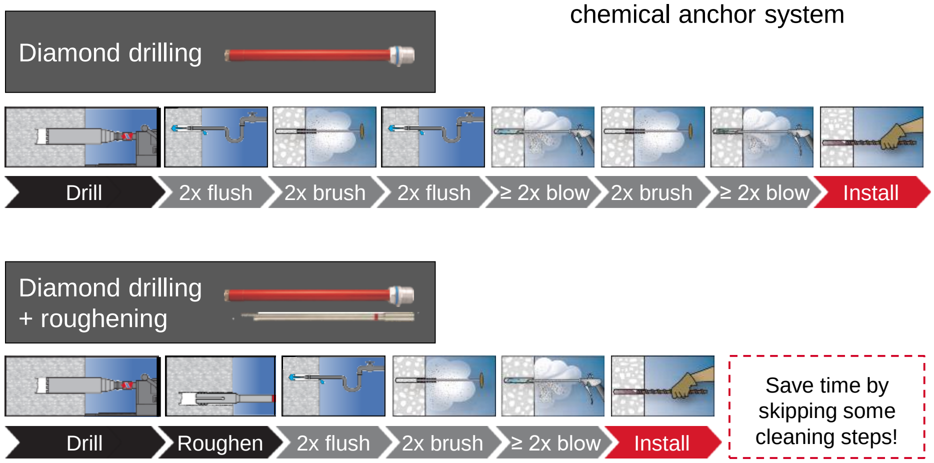






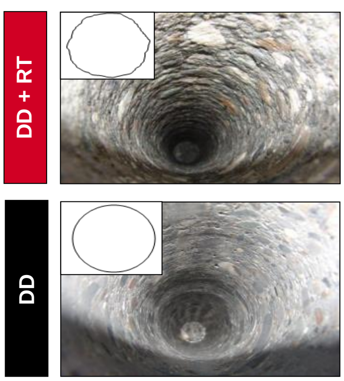
# CLEANING METHODS FOR DIAMOND DRILLING

e.g. Hilti HIT-RE 500 V3
chemical anchor system

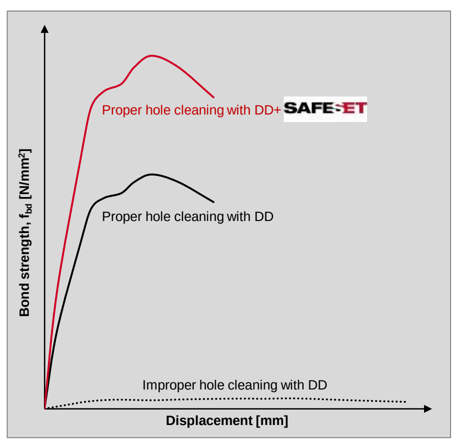



Save time by skipping some cleaning steps!

# ROUGHENING TOOL (RT) ENSURES SAFE AND RELIABLE INSTALLATION IN DIAMOND CORED HOLES




The RT roughens the sides of the smooth diamond cored hole allowing increased mechanical interlock between mortar and concrete.



# INJECTING (CHEMICALS)

**(e.g. for HIT-RE 500 V3 + rebar)**

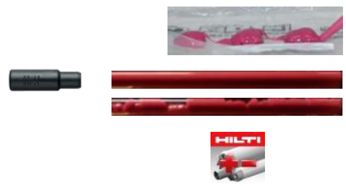
**Tools**

Dependent on product and embedment depth $h_{ef}$

$h_{ef}$ ≤ 1'000 mm | $h_{ef}$ ≤ 2'000 mm | $h_{ef}$ ≤ 3'200 mm

**Pay close attention to…**

- Discarding initial mortar quantity (IFU)
- Avoiding air bubbles (e.g. use piston plug)
- Reducing waste by injecting the right volume



**Special: overhead application**

- Overhead dripping cup + wedges

# ELECTRONIC DISPENSER GIVES YOU BETTER INSTALLATION QUALITY

**Automatic release mechanism (no dripping, accurate filling)**

**Dosing knob for accurate mortar injection : full mortar cost/consumption control**

**Speed regulation for precise bore hole filling**

**High battery capacity : charge it every 60* foil packs!**

* With Battery 22 volts 2.6 Ah

# DOSING KNOB

- Each number displayed on the knob corresponds approximately to a factor of 6 ml.

No mortar can be dispensed when knob is set on «0»

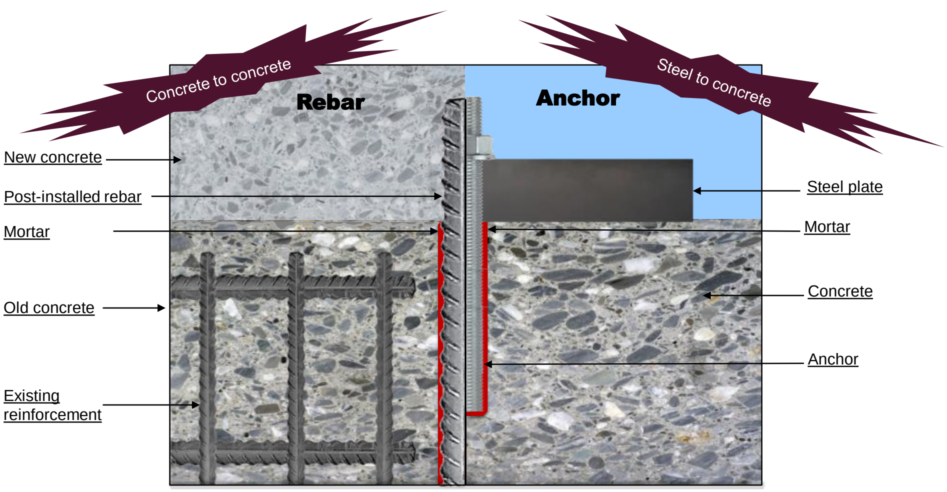
Each sclae number corresponds to a multiple of 6 ml
«3» means 3x6 ml = 18 ml

When set on «▶▶», mortar can be dispensed continuously as long as the trigger is being pressed

Good to know...
Black numbering is impossible to scratch out ! Scale will always be visible !

- Mortar injection will automatically be stopped when required quantity has been dispensed
- It is possible to interrupt mortar flow at any time by releasing pressure on trigger

# REBAR THEORY AND ANCHOR THEORY ARE DIFFERENT THEORIES

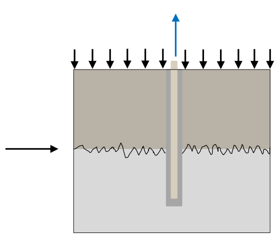


# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | "Rebar theory"<br>Post-installed rebar | "Anchor theory"<br>Bonded anchor |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |

# INFLUENCE OF THE JOINT: SMOOTH VS. ROUGH

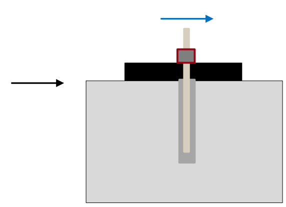
**"Rebar theory"**
**"Design of rebar as a rebar"**



- The post-installed rebar clamps the two faces together, enabling shear transfer through friction acting over the interface surface area. The roughness of the interface surface is critical.
- The post installed rebar acts in tension only.
- Carbonated layer should be removed

(Palieraki et al. 2014; EC2:EN1992-1-1:2004 (6.2.5))

**"Anchor theory"**
**"Design of rebar as an anchor"**



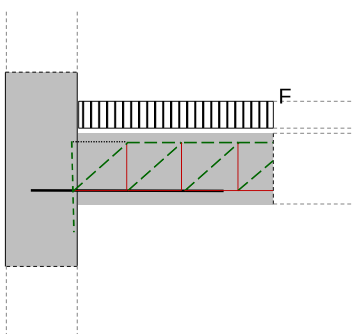
- The anchor takes up the shear load.
- The roughness of the interface surface does not play any role.

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

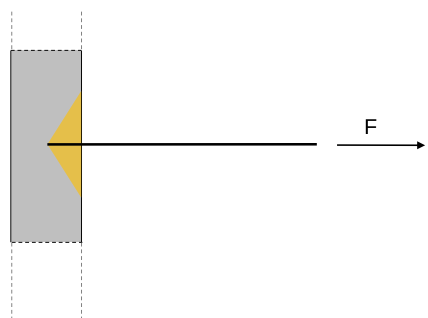
| | **"Rebar theory" Post-installed rebar** | **"Anchor theory" Bonded anchor** |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |

# CONFINED VS. UNCONFINED CONCRETE

**"Rebar theory"**
**"Design of rebar as a rebar"**




**"Anchor theory"**
**"Design of rebar as an anchor"**



# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | "Rebar theory"<br>Post-installed rebar | "Anchor theory"<br>Bonded anchor |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

**"Rebar theory"**
**"Design of rebar as a rebar"**

**Splitting**

**Steel failure**

**Pull out**

The compression strut prevents the concrete cone failure

**"Anchor theory"**
**"Design of rebar as an anchor"**

**Splitting**

**Steel failure**

**Pull out**

**Concrete cone**

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | "Rebar theory"<br>Post-installed rebar | "Anchor theory"<br>Bonded anchor |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |
| **Design steps** | 1. Calculation of steel reinforcement<br>2. Calculation of required anchorage length | 1. Calculation of all characteristic capacities<br>2. Determination of minimum capacity controlling failure anchorage |

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | "Rebar theory"<br>Post-installed rebar | "Anchor theory"<br>Bonded anchor |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |
| **Design steps** | 1. Calculation of steel reinforcement<br>2. Calculation of required anchorage length | 1. Calculation of all characteristic capacities<br>2. Determination of minimum capacity controlling failure anchorage |
| **"Result of theory application"** | Anchorage length ($l_{bd}$) | Capacity of the anchor ($N_{Rk}$) |

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | **“Rebar theory” Post-installed rebar** | **“Anchor theory” Bonded anchor** |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |
| **Design steps** | 1. Calculation of steel reinforcement<br>2. Calculation of required anchorage length | 1. Calculation of all characteristic capacities<br>2. Determination of minimum capacity controlling failure anchorage |
| **“Result of theory application”** | Anchorage length ($l_{bd}$) | Capacity of the anchor ($N_{Rk}$) |
| **Minimum concrete cover** (min (spacing; edge distance)) | According to EC2 | According to ETA |

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

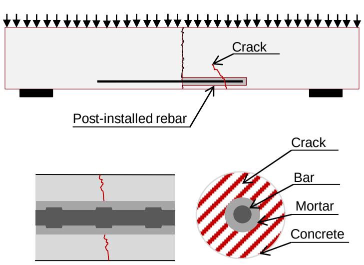
| | **“Rebar theory” Post-installed rebar** | **“Anchor theory” Bonded anchor** |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |
| **Design steps** | 1. Calculation of steel reinforcement<br>2. Calculation of required anchorage length | 1. Calculation of all characteristic capacities<br>2. Determination of minimum capacity controlling failure anchorage |
| **“Result of theory application”** | Anchorage length ($l_{bd}$) | Capacity of the anchor ($N_{Rk}$) |
| **Minimum concrete cover** (min (spacing; edge distance)) | According to EC2 | According to ETA |
| **Allowable anchorage length** | $l_{b,min} \geq \max(0.3 l_{brqd}, f_{yd}; 10\phi; 100mm)$ | $4\phi \leq l_{b,min} \leq 20\phi$ |

# REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

| | "Rebar theory" Post-installed rebar | "Anchor theory" Bonded anchor |
|---|---|---|
| **Load on the bar** | Tension (roughness of joint critical for the shear transfer) | Tension, shear, combination of both |
| **Load transfer mechanism** | Equilibrium with local or global concrete struts | Utilization of concrete tensile strength |
| **Failure modes** | Steel yielding, pull out, splitting | Steel failure, concrete cone failure, pull out, splitting |
| **Design steps** | 1. Calculation of steel reinforcement<br>2. Calculation of required anchorage length | 1. Calculation of all characteristic capacities<br>2. Determination of minimum capacity controlling failure anchorage |
| **"Result of theory application"** | Anchorage length ($l_{bd}$) | Capacity of the anchor ($N_{Rk}$) |
| **Minimum concrete cover** (min (spacing; edge distance)) | According to EC2 | According to ETA |
| **Allowable anchorage length** | $l_{b,min} \geq \max(0.3 l_{brqd}, f_{yd}; 10\phi; 100mm)$ | $4\phi \leq l_{b,min} \leq 20\phi$ |
| **Concrete** | **Uncracked**/cracked | **Cracked**/uncracked |

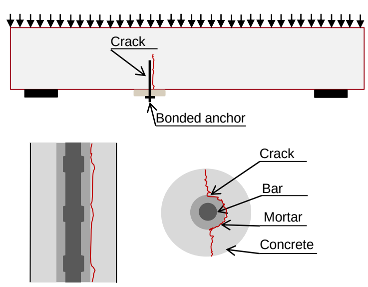
# CONCRETE CONDITIONS: UNCRACKED VS. CRACKED

**"Rebar theory"**
**"Design of rebar as a rebar"**




The crack does not develop parallel to the rebar!

**"Anchor theory"**
**"Design of rebar as an anchor"**



# WHY IS FIRE DESIGN IMPORTANT? FUNDAMENTAL REQUIREMENTS ACCORDING TO EC2

When subjected to fire exposure construction elements performances are reduced causing fall of structures→ Fire causes significant costs losses and deads

**In the event of fire have adequate resistance for the required period of time exposure: concrete structure shall be designed and constructed in a way that they maintain their load bearing function during the relevant fire exposure.**
*(Eurocode 2 provisions)*



# RESISTANCE DESIGN: FIRE ACTION MUST BE SMALLER THAN THE RESISTANCE OF THE BUILDING

$$E_{d,fi} \leq R_{d,t,fi}$$

**$E_{d,fi}$ = design effect of actions for the fire situation**

**$E_{d,fi} = \eta_{fi} E_d$**

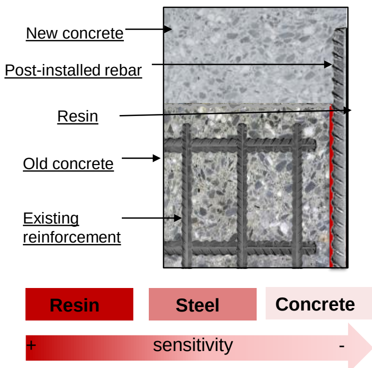
- **$\eta_{fi}$ = reduction factor for the design load level for the fire situation (recommended simplified value = 0,7)**
- **$E_d$ = design value of the corresponding force or moment at t=0, for normale temperature design, for a fundamental combination of actions**

**$R_{d,t,fi}$ = design resistance in the fire situation**

**The design resistance is reduced due to the effect of temperature**

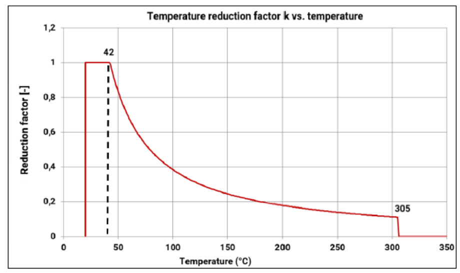
# THE RESISTANCE OF A MEMBER IS FUNCTION OF MATERIAL AND OF TEMPERATURE

**Material**



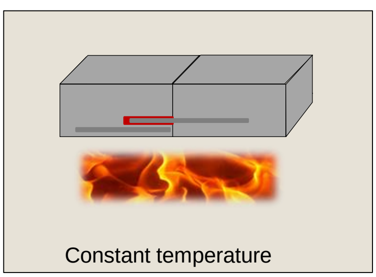

**Temperature**

Figure C1: Example graph of temperature reduction factor $k_{b,fi}(\theta)$ for concrete classes C20/25 for good bond conditions:



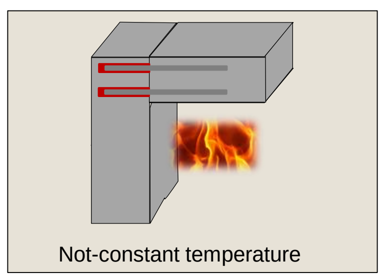

# THE TEMPERATURE ALONG THE ANCHORAGE LENGTH IS NOT ALWAYS CONSTANT: GENERALLY 2 CASES

**Parallel connection**




Temperature along the anchorage length is function of concrete cover and time exposure

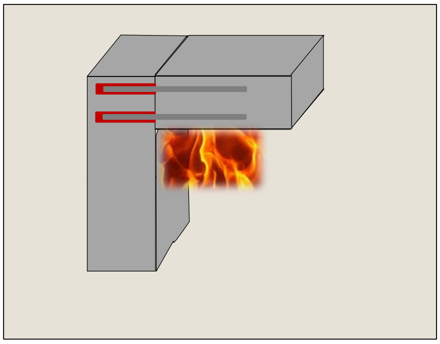
**Anchor connection**



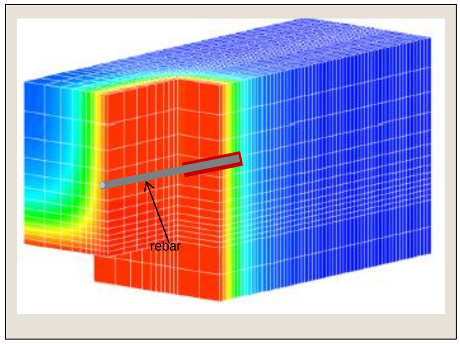

Temperature along the anchorage length is not constant and it is function of length and time exposure

# IN ANCHOR CASES THE TEMPERATURE IS NOT CONSTANT ALONG THE ANCHORAGE LENGTH….

**Design case**



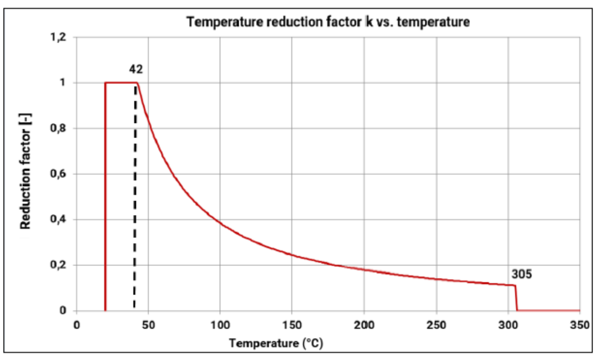
**Temperatue profile**




Temperature along the anchorage length

# PRODUCT SELECTION BASED ON THE ETA SPECIFICATION - PERFORMANCE OF THE PRODUCT

Figure C1: Example graph of temperature reduction factor $k_{b,fi}(\theta)$ for concrete classes C20/25 for good bond conditions:



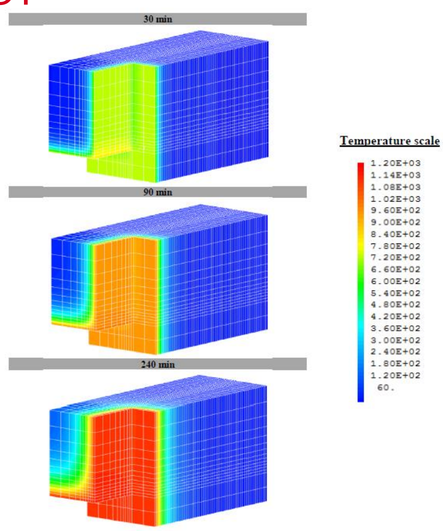
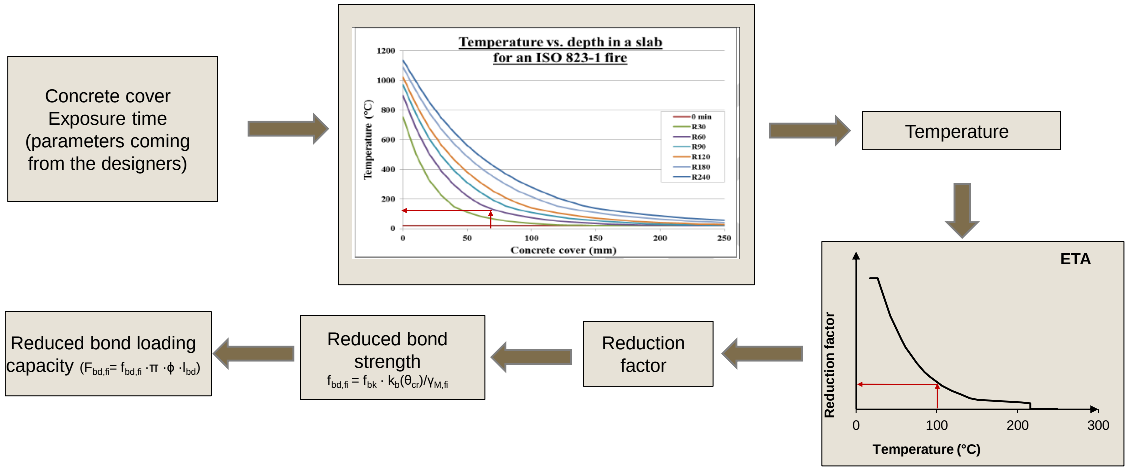




Figure 8 : Temperature fields at 30, 90 and 240 min during an ISO 834-1 fire for the beam-wall connection

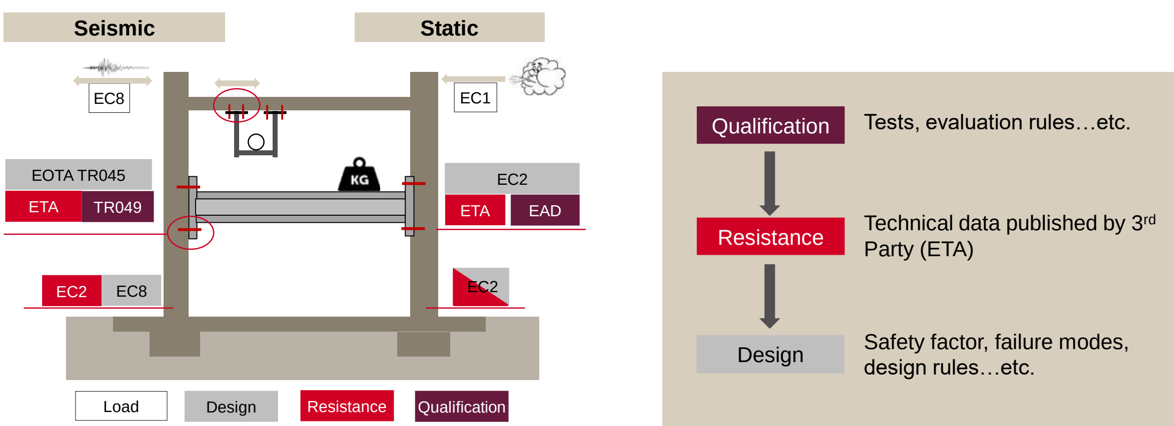
57

# IN PARALLEL CASE THE BOND LOADING CAPACITY CAN BE EASILY CALCULATED IN CASE OF FIRE EVENT



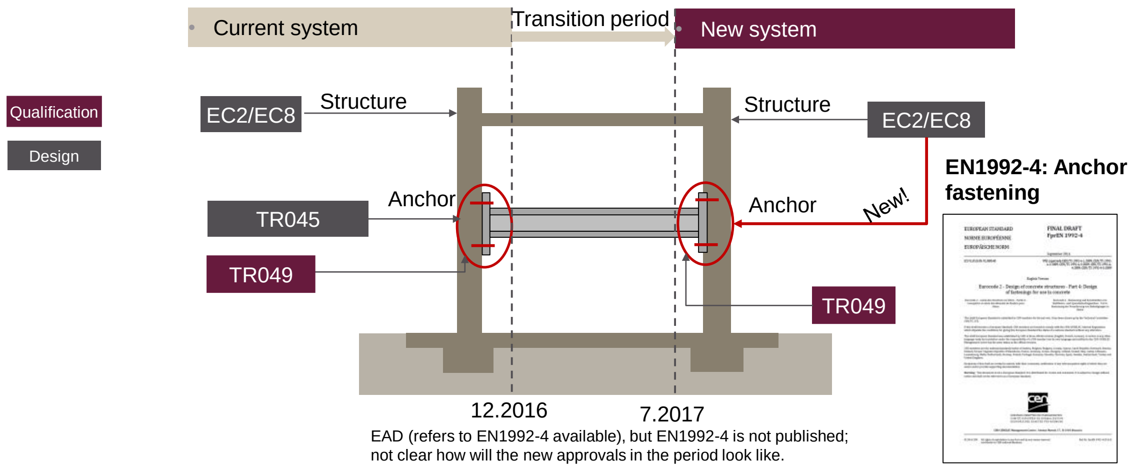

# FUTURE FOR CONSTRUCTION IN MALAYSIA

## SEISMIC DESIGN FOR OUR CONNECTION FOR STRUCTURE



# FUTURE FOR CONSTRUCTION IN MALAYSIA

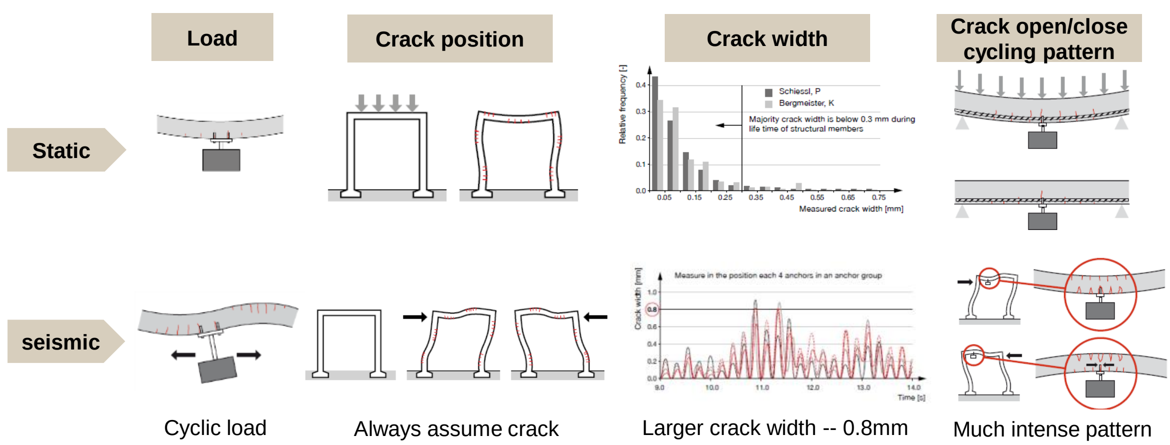
## SEISMIC DESIGN FOR OUR CONNECTION FOR STRUCTURE






# FUTURE FOR CONSTRUCTION IN MALAYSIA

## ANCHOR / FASTENAL NEED QUALIFIED UNDER SEISMIC CONDITIONS



# KEY PARAMETERS ARE FROM RESEARCHES

**BNCS project – HILTI was heavily involved**

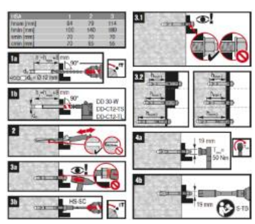

All variables were fully monitored




# IN SHORT, INSTALLING "AS DESIGNED" IS CRUCIAL TO SAVE LIVES & PROTECT ASSETS

**Understand requirements**


**Know the solutions**



**Install them correctly**

**Save time & resources**

**In the end you need to be compliant with the current regulation - e.g.:** EOTA

"(…) It is also assumed that the **anchor (and post-installed rebar) installation is undertaken by trained personnel** under the supervision of the site engineer, to ensure that the specifications are effectively implemented."

# THANKS

# QUESTION & ANSWER