QUALIFICATION OF POST INSTALLED REBAR SYSTEM

Ir Ng Beng Hooi
24th September 2018

100 YEARS

CONTENTS

• 1.0 The New ETA and Consideration behind EAD
• 2.0 Design life for Post Installed Rebar and Anchor
• 3.0 Fire Design for Post Installed Rebar
• 4.0 Seismic for Post Installed Rebar
EAD 330087 INCLUDES THE KEY APPLICATIONS WHICH CAN BE DESIGNED WITH POST-INSTALLED REBAR

SUMMARY OF QUALIFICATION AND DESIGN AS PER EAD 330087 FOR EACH APPLICATION

<table>
<thead>
<tr>
<th>Application</th>
<th>Qualification</th>
<th>Design</th>
</tr>
</thead>
<tbody>
<tr>
<td>Splices</td>
<td>EAD</td>
<td>Eurocode 2</td>
</tr>
<tr>
<td>Compress.</td>
<td>EAD</td>
<td>Eurocode 2</td>
</tr>
<tr>
<td>Simply supp.</td>
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CURRENT APPLICATION OF HILTI METHOD: SIMPLY SUPPORTED AND RIGID CONNECTIONS

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<td>HIT Rebar Method first version for HY200 and RE500V3</td>
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<td>Rigid connect.</td>
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<td>Hilti frame node model based on EC2 + HIT Rebar Method first version for HY200 and RE500V3</td>
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</tbody>
</table>
LIST OF RELEVANT EOTA DOCUMENTS FOR QUALIFICATION OF POST-INSTALLED REBAR

<table>
<thead>
<tr>
<th>Document</th>
<th>Organisation</th>
<th>Roles and functions</th>
<th>Remarks</th>
</tr>
</thead>
</table>

CONTENTS

- 1.0 The New ETA and Consideration behind EAD
- 2.0 Design life for Post Installed Rebar and Anchor
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BACKGROUND

Where do service life requirements come from?

1. Eurocode 1990 “working life category 5” - infrastructure

<table>
<thead>
<tr>
<th>Design working life category</th>
<th>Indicative design working life (years)</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>Temporary structures</td>
</tr>
<tr>
<td>2</td>
<td>10-25</td>
<td>Replaceable structural parts</td>
</tr>
<tr>
<td>3</td>
<td>15-30</td>
<td>Agricultural and similar structures</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
<td>Buildings and other common structures</td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>Monumental buildings, bridges, and other civil structures</td>
</tr>
</tbody>
</table>

2. National standards

Examples: UK, Italy, Cyprus

3. Owners

Example: Burj Khalifa

100 years is gaining worldwide attention – and confusion

Article summary

- 100 years is a hot topic right now, but there is no guidance for how to address it
- Owners must be more clear about their expectations up-front in order to meet them
- “Durability” is a vague word that nobody has seriously considered for service life

Service life for anchors/PIR

- Assessment of anchors and rebar has always implied a 50-year service life
- Where 100 years is needed, it has been handled on a case-by-case basis
- No harmonized standards have accounted for service life, leaving confusion about how to extend it

With the first ETA for 100-year assessment of anchors, Hilti is taking the first step to clearing up the confusion in our industry and taking a role in the bigger conversation about service life.
NEW ETA ADDRESSING THE 100YR SERVICE LIFE TOPIC WHICH FOLLOW A NEW EAD

ETA-16/0143
Dated 14/05/2019
RE500V3 – Anchoring for static/quasi static, seismic in 50 & 100 years service life

ETA-16/0142
Dated 27/05/2019
RE500V3 – Rebar connection for static/quasi static, fire & seismic in 50 years service life

TESTING FOR 50 YEARS

Scope, EAD 330499 (bonded fasteners): The performance characteristics are consistent with the design provisions of EN 1992-4 and are based on a design working life of 50 years.

So, which tests actually connect to 50 years?

<table>
<thead>
<tr>
<th>time/cycle-independent tests</th>
<th>time/cycle-dependent tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>reference tests</td>
<td>freeze/thaw</td>
</tr>
<tr>
<td>“robustness” (dry, wet, flooded, poorly mixed)</td>
<td>durability (alkalinity/sulfur)</td>
</tr>
<tr>
<td>max long/short-term temp.</td>
<td>seismic tests</td>
</tr>
<tr>
<td>maximum torque moment</td>
<td>testing/assessment not tied to 50 years</td>
</tr>
<tr>
<td>installation direction</td>
<td>sustained load</td>
</tr>
<tr>
<td>service condition tests</td>
<td>crack movement</td>
</tr>
</tbody>
</table>

Not relevant for service life

testing/assessment are tied to 50 years

Must be considered in a 100-year EAD
IS DIFFERENCE PULL OUT TEST AT SITE AND SUSTAINED LOAD TEST IN LABORATORY

This Only Test for Installation Workmanship

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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)

EUROPEAN REGULATORY FRAMEWORK FOR POST-INSTALLED REBAR

“Rebar theory”
“Design of rebar as a rebar”

<table>
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<tr>
<th>Product Qualification</th>
<th>Static</th>
<th>Fire</th>
<th>Seismic</th>
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<tbody>
<tr>
<td>EAD</td>
<td></td>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>

| Technical data        |        |      | CSTB regional approval |
| ETA                   |        |      | x                    |

| Design method         |        |      | EC2 based            |
| EC2                   |        |      | EC2 based            |
WHICH ARE THE PARAMETERS TO BE DEFINED FOR A FIRE DESIGN BASED ON EC2?

1. Fire resistance criteria
2. Time exposure
3. Design approach
4. External fire action
5. Fire structural resistance

WHEN SUBJECTED TO FIRE EXPOSURE CONSTRUCTION ELEMENTS RESISTANCE IS REDUCED

- **Steel**
  - EC2
  - Reduction of strength when subjected to high temperatures

- **Concrete**
  - Efficiently behaviour in fire conditions
  - Non-combustible
  - No emissions of smoke
  - Good thermal insulation

- **Mortars**
  - Mortars have high sensitivity to temperatures, it should be part of the consideration in our PIR design
IN THE REGULATORY FRAMEWORK OF REBAR THEORY A NEW EAD FOR FIRE IS AVAILABLE

<table>
<thead>
<tr>
<th>Qualification (&quot;testing&quot;)</th>
<th>Old!</th>
<th>New!</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tech. Data (&quot;approval&quot;)</td>
<td>CSTB, DIBT, Efectis, CTICM have internal qualification criteria* (National level)</td>
<td>EAD «Rebar Fire» (European level)</td>
</tr>
<tr>
<td>Design</td>
<td>DIBT / Efectis / CTICM / CSTB reports</td>
<td>ETA (for post-installed rebar) e.g. ETA 15/0297</td>
</tr>
<tr>
<td></td>
<td>Local design recommendations</td>
<td>EN 1992-1 (Eurocode 2 - Part 1.2)</td>
</tr>
</tbody>
</table>

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

THE NEW EAD INCLUDES METHODS AND CRITERIA FOR ASSESSING THE FIRE PRODUCT PERFORMANCE

The European Assessment Document (EAD) is a harmonised technical specification in the sense of Regulation (EU) No 305/2011 (CPR).

It contains, at least,
- a general description of the construction product and its intended use (Chapter 1 - Scope),
- the list of essential characteristics relevant for the intended use (Chapter 2) and
- methods and criteria for assessing the performance of the product (Chapter 2).
- principles for the applicable factory production control (Chapter 3 - AVCP).

An **EAD-format** has been agreed with the European Commission in March 2015 which is used by all EAD writers aiming at consistency and comparability of the information provided.

**Adopted EADs are used by Technical Assessment Bodies** organized in EOTA for issuing European Technical Assessments (ETA). Titles of adopted EADs according to Annex II.7 to the CPR are announced on this website under "Publications/EADs" once an ETA is issued.

The reference of final EADs is published by the European Commission in the Official Journal of the European Union (OJEU) and provided in NANDO. Once the EAD reference is published in the OJEU, EOTA provides final EADs for download on this website.

Member States or the European Commission may raise **formal objections** against EADs.
IN THE REGULATORY FRAMEWORK OF REBAR THEORY
FIRE PERFORMANCE IS INCLUDED IN THE ETA

Old!

CSTB, DIBT, Efectis, CTICM have internal qualification criteria*
(National level)

Tech. Data
("approval")

DIBT / Efectis / CTICM / CSTB
reports

New!

EAD
«Rebar Fire»
(European level)

Qualification
("testing")

Design

Local design recommendations

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

ETA (for post-installed rebar)
e.g. ETA 15/0297

DIBT AND CSTB REPORTS INCLUDE TABULATED VALUES OF
BOND STRENGTH OR LOAD FOR FEW APPLICATIONS

** Wall to wall connections
** Only member analysis possible
** R criteria

■ Slab to wall connections
■ Only member analysis possible
■ R criteria

Post-installed rebar design in fire

/ 25

Post-installed rebar design in fire

/ 26
THE NEW ETA PROVIDES A BOND STRENGTH AS FUNCTION OF TEMPERATURE

THE FIRE CURVE IS NOW EXTENDED TO 305°C.

• The fire curve shows the mortar behavior in fire
• The reduction factor calculated based on temperature is applied to the characteristic bond strength in order to calculate the fire bond strength

NEW Extension - Up to 305°C!!
- Much more resistance!!

IN THE PAST, THE BEHAVIOR OF THE MORTAR WAS FUNCTION OF APPLICATIONS

Old!

- Bond strength as function of application

New!

- Bond strength as function of temperature: every application is covered!
THE EC2 PROVIDES THE GUIDELINES FOR THE DESIGN OF CONCRETE STRUCTURES IN FIRE CONDITIONS

**Old!**
- CSTB, DIBt, Efectis, CTICM have internal qualification criteria* (National level)
- DIBt / Efectis / CTICM / CSTB reports
- Local design recommendations

**New!**
- EAD «Rebar Fire» (European level)
- ETA (for post-installed rebar) e.g. ETA 15/0297
- EN 1992-1 (Eurocode 2 - Part 1.2)

*No more national approvals will be issued. Some approvals of competitors are valid until 2020.

Post-installed rebar design in fire

THE NEW DESIGN VALUES TAKE INTO ACCOUNT DIFFERENT CONDITIONS

**Old**
- Only conditions assumed in the testing phase are taken into account
- Unknown safety concept developed by CSTB/DIBt internally
- Safety concept not aligned with EC2 safety margins

**New**
- The same logic of cold design is applied and as a consequence several different conditions are taken into account (in a cold design):
  - Robusteness of the mortar
  - Robusteness of the installation
  - Long term behavior
  - Corrosion
  - Cyclic temperatures
  - Cracked concrete
- Safety concept in line with EC2

Post-installed rebar design in fire
THE CONCRETE COVER IS A PARAMETER CONSIDERED IN THE FIRE DESIGN TABLES FOR HIT-RE 500 V3

Old

| Concrete cover is not a parameter |

New

| Concrete cover affects the heating transfer along the anchorage length |

Heat is transferred to the rebar via concrete cover

Rebar transfers heat to the mortar
TO SIMPLIFY THE RESISTANCE DESIGN, HILTI PROVIDES DESIGN DATA FOR THE MOST COMMON APPLICATIONS

Bond strength or bond loading for limited/specific cases

Slab-to-slab connections

Slab-to-wall connections

Constant temperature

Not-constant temperature

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

Concrete cover
Exposure time (parameters coming from the designers)

Temperature

Reduced bond loading capacity \( f_{bd,fi} = f_{bd} \cdot k_b(\theta_{cr})/\gamma_{M,fi} \)

Reduced bond strength \( f_{bd,fi} = f_{bd} \cdot k_b(\theta_{cr})/\gamma_{M,fi} \)

Reduction factor

Post-installed rebar design in fire
DESIGN VALUES FROM HILTI TABLES ARE USED IN THE FIRE DESIGN OF SYSTEM CONNECTIONS BASED ON EC2

- \( E_{d,fi} \leq R_{d,fi} \)
- \( E_{d,fi} \) = design effect of actions for fire situation
  \[ E_{d,fi} = \eta_fi \cdot E_d \]
  - \( \eta_fi \) = 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 for normal temperature design, for a fundamental combination of actions

- \( R_{d,fi} \) = design resistance in the fire situation
  \[ R_{d,fi} = \min(F_{bd,fi}; F_{s,fi}) \]
  - \( F_{bd,fi} \) = fire bond resistance
  - \( F_{s,fi} \) = fire steel resistance

\[ F_{bd,fi} < F_{s,fi} \]

PROFIS PROVIDES SOLUTIONS FOR POST-INSTALLED REBAR SYSTEM CONNECTIONS SUBJECTED TO FIRE
CONTENTS

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NEW DEVELOPMENT OF THE QUALIFICATION CRITERIA FOR REBAR IN SEISMIC

This European Assessment Document (EAD) covers post-installed rebar in seismic loading. This EAD covers post-installed reinforcing bar (rebar) connections designed in accordance with EN 1992-1-1 and EN 1990-1-3.

The post-installed rebar connection consists of a mortar and an embedded straight ribbed (deformed) reinforcing bar complying with EN 10080-1. Class C, classes B and C.
MORE THAN 2 YEARS OF WORK...WITH HUNDREDS OF TESTS!

THE QUALIFICATION PROCEDURE ENSURES THAT THE PRODUCT IS TESTED AS PER THE GUIDELINE

<table>
<thead>
<tr>
<th>Application</th>
<th>Qualification guideline</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Image]</td>
<td>[Image]</td>
<td>[Image]</td>
</tr>
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</table>

Testing + Assessment

ETA

*: Technical Assessment Body
Based on the qualification process, PIR should behave similarly to cast-in in seismic applications.

**Cast-in rebar**

1. Load transferred by mechanical interlock provided by the rebar ribs.
2. Mechanical interlock develops compression struts.
3. Struts lead to rotational tensile stresses perpendicular to the loading direction.

**Post-installed rebar**

1. Load from the rebar transferred to the concrete via the mortar at the interface.
2. Transfer occurs due to adhesion and micro-interlock at the rough interface caused by the drilled hole.

The qualification ensures that the product is suitable for seismic applications.

Ensure the suitability of the product for the application where it is used for.

Ensure the resistance of the product subjected to the different conditions has been tested for.

Ensure the compatibility of the product with the code design.

Ensure that the compatibility of the product with standardized and safe installation methods.

Ensure the resistance of the product subjected to the different conditions has been tested for.
EUROPEAN REGULATORY FRAMEWORK FOR POST INSTALLED REBAR

“Rebar theory”
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<th>Design method</th>
<th>EC2</th>
<th>EC2</th>
<th>EC8 based</th>
</tr>
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ETAG QUALIFICATION FOR ANCHORS CONSIDERS TWO CONDITIONS C1 AND C2

Qualification for C1

Qualification for C2

TR 049

/
PEAK GROUND ACCELERATION AND BUILDING CATEGORY ARE DIFFERENT FOR C1 AND C2

<table>
<thead>
<tr>
<th>Seismicity level</th>
<th>Importance Class acc. to EN 1998-1:2004, 4.2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>$a_2 - S$</td>
</tr>
<tr>
<td>Very low$^a$</td>
<td>$a_2 - S \leq 0.05 \ g$</td>
</tr>
<tr>
<td>Low$^b$</td>
<td>$0.05 \ g &lt; a_2 - S \leq 0.10 \ g$</td>
</tr>
<tr>
<td>&gt; low</td>
<td>$a_2 - S &gt; 0.10 \ g$</td>
</tr>
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<td></td>
<td>I</td>
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</tbody>
</table>

- Category C1 or C2 is function of seismicity level (PGA) and importance class of the building.

SEISMIC C1 QUALIFICATION CONSIDERS CYCLIC LOADING AND STATIC CRACKING (ANCHOR IS IN THE CRACK)

- **Tensile test**
  - Static crack opened at 0.5 mm
- **Shear test**
  - Static crack opened at 0.5 mm

$^a$ The values defining the seismicity levels are may be found in the National Annex of EN 1998-1.

$^b$ Definition according to EN 1998-1:2004, 3.2.1.

$^c$ $a_2$ = design ground acceleration on Type A ground (EN 1998-1:2004, 3.2.1), $S$ = soil factor (see e.g. EN 1998-1:2004, 3.2.2).

$^d$ C1 for Type ‘B’ connections (see 5.1)

$^e$ C2 for Type ‘A’ connections (see 5.1)
SEISMIC C2 QUALIFICATION CONSIDERS CYCLIC LOADING AND CYCLIC CRACKING (ANCHOR IS IN THE CRACK)

THE CYCLIC ACTION CAN SIGNIFICANTLY AFFECT THE PERFORMANCE

<table>
<thead>
<tr>
<th>Φ=16 mm</th>
<th>Φ=20 mm</th>
<th>Φ=24 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>5.5</td>
<td>5.4</td>
<td>5.1</td>
</tr>
</tbody>
</table>

-42%  -46%
WHY THE QUALIFICATION IS DIFFERENT FOR REBAR? 1) BECAUSE THE CRACK IS NOT PARALLEL TO A REBAR!

2) BECAUSE THE REBAR IS NOT A SINGLE POINT OF CONNECTION
3) ANCHORAGE LENGTH OF REBAR IS IN GENERAL MUCH LONGER THAN AN ANCHOR’S

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

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

Post-installed rebar

Bonded anchor

\[ l_{\text{b,min}} = \max(0.3l_{\text{breq}}, f_{\text{yd}}; 10\phi; 100\text{mm}) \leq l_{\text{bd}} \leq 60 \phi \]

\[ 4\phi \leq h_{\text{eff}} \leq 20\phi \]

CAST-IN FAILS FOR YIELDING, SPLITTING AND PULL OUT: IS PIR EQUAL TO CAST-IN WHEN SUBJECTED TO CYCLIC?

Static failure modes

- Splitting
- Pull out
- Yielding

Scope of qualification

Assess the equivalence of post-installed rebar with cast-in in terms of bond strength degradation and energy dissipation:

- In splitting: the bar is very close to the edge
- In pull-out: the bar is far from the edge
AS PER CAST-IN BAR, PIR BOND STRENGTH IS NOT FUNCTION OF SEISMIC ZONE (1/2)

Seismic design

- External action due to seismic load
  - Peak ground acceleration
  - Type of ground
  - Type of structure

- Internal reaction of structure
  - Ductility class
  - Design of details

The action on the structure is function of seismic zone

The reaction is a consequence of how the structure has been designed (same logic as per cast-in design)

AS PER CAST-IN BAR, PIR BOND STRENGTH IS NOT FUNCTION OF SEISMIC ZONE (2/2)

Anchor design

Position of the anchor
The anchor is installed in the crack. The performance of the anchor in cracked concrete is lower than non-cracked concrete.

C1 and C2 qualification
The two categories take into account the performance of the anchor installed in a crack subjected to loading displacement. C2 is the category for structural elements.

Seismic zone is not considered in the reaction
Seismic zone is not considered in the performance of the anchor. The anchor is tested under standardized displacement/force which does not consider the position of the building.

Rebar design

Position of the rebar
In general situations, the crack does not develop along the rebar. Rebar connections are not a single point of connection, but rather a multiple connection system. Embedment depth of rebar is significantly higher than anchors.

Seismic qualification
The seismic qualification takes into account the performance of a post-installed rebar subjected to cyclic loading/displacement.

Seismic zone is not considered in the reaction
Seismic zone is not considered in the performance of the rebar. The rebar is tested under standardized displacement/force which does not consider the position of the building.
REBAR THEORY AND ANCHOR THEORY ARE DIFFERENT THEORIES

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

<table>
<thead>
<tr>
<th>Seismic qualification</th>
<th>“Rebar theory” Post-installed rebar</th>
<th>“Anchor theory” Bonded anchor</th>
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<td></td>
<td>To check the equivalence with cast-in. In case of non-equivalence, the bond strength is reduced to take into consideration the additional degradation of the bond strength when subjected to cyclic loading.</td>
<td>To assess the performance in cracked concrete subjected to cyclic loading.</td>
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REBAR THEORY: EQUIVALENCE WITH CAST IN BAR
ANCHOR THEORY: PERFORMANCE IN CRACKED CONCRETE

“Rebar theory”
“Design of rebar as a rebar”

“Anchor theory”
“Design of rebar as an anchor”

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

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</tr>
<tr>
<td>Position of anchor/rebar with respect to the crack</td>
<td>Uncracked concrete</td>
<td>Parallel to the crack</td>
</tr>
</tbody>
</table>
CONCRETE CONDITIONS: UNCRACKED VS. CRACKED

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

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

The crack does not develop parallel to the rebar!

REBAR THEORY VS. ANCHOR THEORY: MAIN DIFFERENCES

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THE DESIGN ANCHORAGE LENGTH IS FUNCTION OF REQUIRED ANCHORAGE LENGTH AND FACTORS $\alpha_I$

$$F_{bd} = f_{bd} \cdot \tau \cdot \Phi \cdot l_{bd} \quad \Rightarrow \quad l_{bd} = \alpha_1 \cdot \alpha_2 \cdot \alpha_3 \cdot \alpha_4 \cdot \alpha_5 \cdot l_{b,rqd} \geq l_{b,min}$$

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<td>$l_{b,rqd} = (\Phi/4)(\sigma_{sd,seism}/f_{bd,seism}) \Rightarrow \text{using } f_{yd} \text{ instead of } \sigma_{sd,seism} \text{ is strongly recommended}$</td>
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<td>$l_{b,min}$</td>
<td>$\max(0.3l_{brqd,yd}; 10\phi; 100\text{mm}) \Rightarrow \text{end bars}$</td>
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IN PROFIS REBAR: SELECT SEISMIC DESIGN TO TAKE INTO ACCOUNT REDUCTION OF PERFORMANCE

THANK YOU