Post-installed reinforcement bars in structural connections

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21 November, 2014
Agenda

- Applications and different methods
- Internal stresses in the connections
- Qualification of an adhesive mortar
- Designing and detailing the connection
- Conclusions
Post-installed bars are often required to correct jobsite errors but can also be a favored method.

<table>
<thead>
<tr>
<th>Misplaced or missing bars</th>
<th>Consciously planning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Due to… incorrect positioning - or - bars movement when pouring and vibrating the concrete</td>
<td>- Contractor preferred method (e.g. to avoid jobsite errors)</td>
</tr>
<tr>
<td></td>
<td>- Easier/only possibility due to construction process (e.g. slurry walls)</td>
</tr>
<tr>
<td></td>
<td>- Extension of existing building (e.g. height extensions)</td>
</tr>
<tr>
<td></td>
<td>- Strengthening / retrofitting for seismic loading</td>
</tr>
</tbody>
</table>
Post-installed bars grants flexibility required in new constructions or renovation works (1/2)

<table>
<thead>
<tr>
<th>Connection of new slabs</th>
<th>Balcony extensions</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="connection-of-new-slabs-1.png" alt="Image" /></td>
<td><img src="balcony-extensions-1.png" alt="Image" /></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Close openings / slab enlargement</th>
<th>Staircase connections</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="close-openings-1.png" alt="Image" /></td>
<td><img src="staircase-connections-1.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Post-installed bars grants flexibility required in new constructions or renovation works (2/2)

New columns / Columns extensions

Bridge enlargement

Beam connections

Wall extension
Some of the methods for post-installing rebars are limited to new construction

**Mechanical couplers**
- Very attractive method for pre-fabricated slabs
  - Risk of misplacement
  - Localized 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 pricy solution
  - Limited to smaller bars
  - Limited to new projects

**Perforated formwork**
- Positioning of the bars mostly guaranteed
  - Holes in formwork neutralizes reutilization
  - Leakage of cement reduces concrete quality in the connection
  - Limited to new projects
Using high-level adhesives combines safety with jobsite flexibility and efficiency

<table>
<thead>
<tr>
<th>Chiseling, Welding</th>
<th>Cementitious grouts</th>
<th>Adhesive mortars</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Chiseling, Welding Image" /></td>
<td><img src="image2" alt="Cementitious Grouts Image" /></td>
<td><img src="image3" alt="Adhesive Mortars Image" /></td>
</tr>
<tr>
<td>Load transferred directly to the existing bars</td>
<td>Low cost of grout per milliliter</td>
<td>Mixture quality ensured by dispenser units</td>
</tr>
<tr>
<td>Risk of creating concrete cracks along the bars</td>
<td>Can only be installed downwards or inclined</td>
<td>Small sized diameter and high bond strength</td>
</tr>
<tr>
<td>High dependency of the quality of the welding</td>
<td>Dubious control over the mixture done on jobsite</td>
<td>Drilling required</td>
</tr>
<tr>
<td>Welding can’t be done in unfavorable weather</td>
<td>Typical large drilling diameter vs bar size</td>
<td>Higher cost of mortar per milliliter</td>
</tr>
</tbody>
</table>
Post-installed rebar application are studied and designed in a very different way than anchors.

**MATERIALS:** Chemical mortar + reinforcement bar (aka rebar)

**APPLICATION:** Connecting new concrete to existing concrete

This clearly referred to as a post-installed rebar connection.

Anchoring connection that uses a rebar in lieu of a threaded bar.

**Adhesive mortars are used but this is the only similarity to anchoring.**
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A rebar under tension develop in the concrete compression and resulting tension stresses
To avoid direct tension on the concrete, tension loads are usually transferred by lap splices

- For a single rebar, the tension forces are transferred via compression struts into the concrete, the concrete would be taking up tension!

- Splices are created exactly to ensure that tension is transferred from one bar to the other bar “releasing” the concrete from tension stress.
Shear also develop tension in the concrete and stirrups aid to transfer stress to the supports

However, not only the stirrups transfer the shear to the supports…
Even in concrete sections in pure shear stress, longitudinal bars are always under tension

- For a simply supported element, the bottom longitudinal bars will always be in tension, even at the support; in this case due to shear

Load on longitudinal bars: moment \( F^M = \frac{M}{z} \) & shear \( F^V = \frac{V}{2} \cotg \theta \)
When no splice is present, there must be always a strut to avoid concrete failures in tension

- The bar is in tension yet the surrounding concrete is in compression which “releases” the concrete from tension stress.

In the case of post-installed bars there must be a qualification
The load transfer of a post-installed rebar must be assessed to be said equivalent to cast-in.

**Cast-in rebar**

1. mechanical interlock between ribs and the concrete

**Post-installed rebar**

1. mechanical interlock between ribs and mortar layer
2. adhesion and micro interlock from mortar into the concrete

**Adhesion and installation of a post-installed rebar must be checked**
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 Regulation landscape EU and US guide the assessment of mortars for post-installed rebars

- Both EU (since 2006) and US (since 2013) frameworks guide the assessment of adhesive mortars for post-installed rebar applications.

<table>
<thead>
<tr>
<th>Rebar resistance</th>
<th>US (UBC / IBC)</th>
<th>EU (EOTA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualification (“testing”)</td>
<td>ICC-ES AC308 ACI 355.4</td>
<td>EOTA TR023</td>
</tr>
<tr>
<td>Design method</td>
<td>ACI 318 Chapter 12</td>
<td>Eurocode 2 EN 1992</td>
</tr>
</tbody>
</table>
The testing is extremely comprehensive and check reliability, installation and performance

- The tests (13 sets!) are conducted to establish suitable in terms of:
  - **Bond strength** for low and high concrete strength
  - **Bond transfer behavior** ensured even if splitting controls
  - **Sensitivity** to cleaning, extreme service temperatures, installation orientation, alkalinity/acidity exposure…
  - **Embedments of 60d**, aptitude of the system (mortar, installation gear)
  - **Corrosion protection** of the rebar
  - **Seismic** tension load behavior (US only)

The full system performance is crucial in the qualification, not only adhesive bond strength determined in optimum conditions
One key assessments is to identify if the mortar is able to transfer the load as a cast-in (1/2)

- Bond/splitting behavior is crucial to allow and harmony of load transfer between the post-installed and the cast-in bars in a splice.

Reference test: Cast-in bar spliced with another cast-in bar

University of Stuttgart – SPIETH, OZBOLT, ELIGEAUSEN, APPL – “Numerical and Experimental Analysis of Post-Installed Rebars Spliced with Cast-in-Place Rebars”. International Symposium on Connections between Steel and Concrete.
One key assessments is to identify if the mortar is able to transfer the load as a cast-in (2/2)

- Bond/splitting behavior is crucial to allow and harmony of load transfer between the post-installed and the cast-in bars in a splice.

Not all “epoxy” have the same behavior!
Too high stiffness hints to an unexpected splitting
Some mortars have a huge sensitivity to the drilling method, even more than to cleaning

- Even if it seems a jobsite topic, this should be covered during the design and specification of the post-installed rebar solution.

Anticipating jobsite mistakes, it’s suggested to specify a mortar system approved to hammer and diamond drilling
Hole cleaning impact of adhesive mortars is also of highest relevance in rebar applications

- Traditional essential process after drilling…

- Cleaning is not required using a mortar approved for drilling with the Hilti Hollow Drill Bits (automatic dust removal during drilling)
Finally, it must be guaranteed that there will be mortar throughout the embedded rebar

- It’s quite anticipated that for embeddings above 250mm (10in) during a traditional injection air pockets will remain in the hole.

  OK: Load fully transferred, theory meets practice

  NOT OK: current situation not sufficient to transfer load

- There are solutions to ensure zero air pockets as it is the case of Hilti Piston Plug
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Embedment for static loading and seismic ordinary / intermediary ductility structures

- ACI318 Chapter 12 expression to calculate development length:

\[
l_{bd} = \left( \frac{3}{40} \frac{f_y}{\lambda_a \sqrt{f'_c}} \frac{\psi_t \psi_e \psi_s}{\frac{c_b + K_{tr}}{d_b}} \right) \cdot d_b \]

Min. embedment for tension = 12in

- Simplification of the expression for PI rebars (max c/d = 2.5):

\[
l_{bd} = \left( \frac{3}{40} \frac{f_y}{\sqrt{f'_c}} \frac{\psi_s}{\frac{c}{d}} \right) \cdot d
\]

\[
c = \min(c_x, c_y, s/2)
\]
Max (c/d) = 2.5

\[
\psi_s = 1.0 \quad \text{Bar} \geq \#7 \ (0.875\text{in})
\]
\[
\psi_s = 0.8 \quad \text{Bar} < \#7 \ (0.875\text{in})
\]

\[
\lambda_a = 1.0 \quad \text{Assuming normal weight concrete}
\]

\[
K_{tr} = 0 \quad \text{No influence of reinforcement}
\]

\[
\psi_t = 1.0 \quad \text{Assuming non-coated rebars}
\]

\[
\psi_e = 1.0 \quad \text{Do not experience top-bar effects}
\]
Embedment for seismic loading in special ductility reinforced concrete moment frames

- ACI318 Chapter 21 expression to calculate development length:

\[
l_d = \left( \frac{1}{65} \frac{f_y}{f'_c} \right) \cdot d_b \times 2.5
\]

Depth of the concrete cast in one lift beneath the bar ≤ 12 in

\[
l_d = \left( \frac{1}{65} \frac{f_y}{f'_c} \right) \cdot d_b \times 3.25
\]

Depth of the concrete cast in one lift beneath the bar > 12 in

- Comparison to the standard Chapter 12 calculation

For c/d = 2.5 (max value)

\[
l_{bd} = \left( \frac{1}{33} \frac{f_y}{f'_c} \right) \cdot d_b
\]

Depth of the concrete cast in one lift beneath the bar ≤ 12 in

Bar size ≥ #7

Depth of the concrete cast in one lift beneath the bar > 12 in

Increase factor:

Depth of the concrete cast in one lift beneath the bar ≤ 12 in → 1.25

Depth of the concrete cast in one lift beneath the bar > 12 in → 1.63
Development lengths = cast-in (ACI 318 Chapter 12)
concrete 4000psi, steel Gr.60, static, ordinary/intermediate seismic

**Straight bars**

<table>
<thead>
<tr>
<th>Embedment (in)</th>
<th>Confinement* (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>#3</td>
</tr>
<tr>
<td>1.5</td>
<td>#4</td>
</tr>
<tr>
<td>2.0</td>
<td>#5</td>
</tr>
<tr>
<td>2.5</td>
<td>#6</td>
</tr>
<tr>
<td>3.0</td>
<td>#7</td>
</tr>
<tr>
<td>3.5</td>
<td>#8</td>
</tr>
<tr>
<td>4.0</td>
<td>#9</td>
</tr>
<tr>
<td>4.5</td>
<td>#10</td>
</tr>
</tbody>
</table>

*edge distance or 1/2 rebar spacing

**Spliced bars**

<table>
<thead>
<tr>
<th>Embedment (in)</th>
<th>Confinement* (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Not possible to PI bars</td>
</tr>
<tr>
<td>1.5</td>
<td>#3</td>
</tr>
<tr>
<td>2.0</td>
<td>#4</td>
</tr>
<tr>
<td>2.5</td>
<td>#5</td>
</tr>
<tr>
<td>3.0</td>
<td>#6</td>
</tr>
<tr>
<td>3.5</td>
<td>#7</td>
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<tr>
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<td>#9</td>
</tr>
<tr>
<td>5.0</td>
<td>#10</td>
</tr>
</tbody>
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*edge distance or 1/2 rebar spacing

2500 concrete → +25%
6000 concrete → -20%
Designing per any concrete code, splitting and bond failure are the failure modes to precluded

- Generically...

![Diagram showing splitting failure, bond failure, rebar close to an edge, and rebar away from the edge.](image-url)
For straight bar connections, embedment is limited by concrete splitting until bond governs the resistance.

<table>
<thead>
<tr>
<th>Very close edges or spacing</th>
<th>No edges, no near bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bond that can be developed</td>
<td>Bond that can be developed</td>
</tr>
<tr>
<td>Cast-in</td>
<td>Cast-in</td>
</tr>
<tr>
<td>Post-inst.</td>
<td>Post-inst.</td>
</tr>
</tbody>
</table>

→ Splitting limits the resistance

→ Bond limits the resistance

* "bond" (mechanical interlock) between rebar ribs and the concrete

HIT Rebar method bridge the 2 opposite cases
Due to extensive 20 years of internal testing, Hilti is able to identify the bond/splitting behavior for cases above.

Extension for post-installed bars with large cover (unique for Hilti)

\[
\text{Utilizable bond strength } f_{bd} \text{ [N/mm}^2\text{]}
\]

Bond strength of used adhesive (depending on mortar and conditions)

ACI concrete «bond» limit
Embedment lengths – all possible methods
concrete 4000psi, steel Gr.60, continuous row of straight bars

ACI 318 Chapter 12 (cast-in)  |  ACI 318 Chapter 12 extension (Hilti)

Bar #6 (φ19)

Bar #8 (φ25)

Drill bit TE-YX 21" (also available 36")

Drill bit TE-YX 36"

-31%

-46%

-23%

-38%

2500 concrete → +25%
6000 concrete → -20%
Post-installing a rebar is not only the right selection of adhesive but it’s truly a system

- Compared to the traditional anchor embedments, the longer embedments installation highlight the importance of installation.

**Anchor design ~10d/~15d (ACI 318 Appendix D)**

**Increased installation importance**

**Equal to cast-in ~35d/45d (ACI 318 Chapter 12)**

**Surface preparation:**
- Roughening the interface

**Drilling:**
- Different drilling methods

**Cleaning the hole:**
- Removing the dust

**Injection:**
- Avoiding air pockets

The specification of a post-installed rebar connection should indicate clearly surface preparation and installation gear in lieu of just mortar.
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Main takeaways

• Among all methods for post-installing rebars, adhesive mortars best combine safety and flexibility for both design and installation.

• Post-installed rebars can ensure a truly monolithic connection and as a result the bars will be only under tension, as regular cast-in bars.

• In the case of properly qualified adhesive mortars, the design of post-installed rebars can be done exactly as a cast-in.

• A proper specification should include the bars diameter and spacing, the drilling depth, the adhesive mortar yet also installation notes.

• For the specific case of Hilti solutions, due to the extensive testing, embedments of straight bar connection can be significantly reduced.
Thank you for your attention!

Jorge Gramaxo
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Hilti Corporation

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