ACI Web Sessions

This ACI Web Session includes three speakers presenting at the ACI Xtreme Concrete convention held in Chicago, IL, March 21st through 25th, 2010. Additional presentations will be made available in future ACI Web Sessions.

Please enjoy the presentations.

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Adhesive Anchors
Requirements for their reliable use in concrete construction
by Werner Fuchs, Rolf Eligehausen
Institute of Construction Materials
University of Stuttgart

Applications:

Adhesive anchors - their reliable use in concrete

Applications:
Adhesive anchors - their reliable use in concrete

Adhesive anchors - Requirements for their reliable use in concrete construction

Detailed information:
What about adhesive anchors?

<table>
<thead>
<tr>
<th>Topic</th>
<th>No. of presentations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Provisions, Qualification, Design</td>
<td>2</td>
</tr>
<tr>
<td>Installation</td>
<td>3</td>
</tr>
<tr>
<td>Design</td>
<td>4</td>
</tr>
<tr>
<td>Sustained load</td>
<td>4</td>
</tr>
<tr>
<td>Environmental conditions</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
</tbody>
</table>

Adhesive anchors - their reliable use in concrete

Reliable connections with adhesive anchor systems

Reliability depends on the amount of human errors and their effect on the structural behavior of adhesive anchors

- Requirement:
  - Reduction of erroneous contributions of humans to the adhesive anchor application process

  - Error-tolerant products
  - User-centered design
  - Safe installations
  - Qualified supervision, inspection

Adhesive anchors - their reliable use in concrete

Requirements to ensure reliable fastenings

Producer
- efficient fastening system

Engineer
- accurate design

User
- correct installation

Reliable fastening

Adhesive anchors - their reliable use in concrete

Actual situation

Adhesive anchors - their reliable use in concrete

ACI 2011 - Approach for reliable fastenings

ACI 318 App. D
- Adhesive Anchor Design

ACI 355 X
- Adhesive Anchor Prequalification

ACI 601
- Adhesive Anchor Installer Certification
Adhesive anchors - their reliable use in concrete

Adhesive anchor selection - designer

Anchor selection is governed by:

- Loading conditions: static, seismic, load direction...
- Location of fastening: edge distance, spacing, member depth...
- Concrete, characteristics, condition: strength, cracked, uncracked...
- Environmental conditions: elevated temperatures, freeze/thaw conditions, humidity...
- Location of adhesive anchor: installation conditions, detailing...
- Installation direction: vertical, horizontal, overhead...
- Environmental conditions: concrete temperature, submerged/concrete...

Service life

Installation

Adhesive anchor design - designer

Adhesive anchor design is based on ACI 318-08, App. D (mechanical anchors)

Modifications:

- Verification of the sustained load
  ACI 308: reduction factor \( \phi_{\text{rel}} = 0.75 \)
  ACI 318, App. D: reduction factor \( \phi_{\text{rel}} = 0.55 \)
- Prediction of the pull-out capacity by equations

Design provisions of AC 308 and ACI 318 represent the state-of-art in adhesive anchor design

Adhesive anchors - their reliable use in concrete

Parameters influencing the bond strength of adhesive anchors - optional in prequalification

- Hole cleaning, installation
  water filled hole, submerged concrete
- Installation
  decreased installation temperature, < 50° F
- Chemicals
  resistance to sulfur
- Installation direction
  overhead
- Seismic loading

Designer's task:

Compare exactly the requirements resulting from design for service life and installation with the field of application given in the ESRRs of products from different manufacturers

Adhesive anchors - their reliable use in concrete

Adhesive anchor prequalification

Types of tests:

- Identification test
  compliance with fabrication requirements, establish baseline for quality assurance
- Reference tests
  yield values to be compared with the results of the reliability tests
- Reliability tests
  establish anchor categories used in ACI 318, App. D, demonstrate sensitivity to effects from possible deviations from the MPII likely to occur on-site and deviations occurring in service
- Service condition tests
  establish characteristic resistance to be used in design

Reliability tests do not cover gross installation errors. They shall be prevented by appropriate installer training and qualified site inspection

Adhesive anchors - their reliable use in concrete

Characteristics influencing the bond strength of adhesive anchors - mandatory in prequalification

- Product
- Drilling method
- Concrete
  low strength, high strength, regional variation
- Hole cleaning, installation
  dry and saturated concrete
- Mixing
  Cracked concrete
  only for intended use in cracked concrete
- Installation direction
  vertical down
- Temperature
  long-term: > 110° F, short-term: > 176° F
  Freeze/thaw
  Sustained loading
  Chemicals
  resistance to alkalinity
- Curing time
  standard temperature, 72° F

Adhesive anchors - their reliable use in concrete

Adhesive anchor installation

Actual situation:

- Qualification of the installer is not required
- Special inspection is required
- to take care of
  + storage conditions of the adhesive
  + application of the correct installation equipment
  + sufficient hole cleaning
  + correct insertion of the steel element
  + adherence with the cure time
  …

Special inspector must be aware of the negative impact of deviations from the Manufacturer’s Product Installation Instruction (MPII) on the adhesive anchor performance
Adhesive anchors - their reliable use in concrete

Adhesive anchor installation
Example: Borehole cleaning in Germany
Injection system, required borehole cleaning: blowing and brushing
Installation performed by an appropriately qualified person

Requirement by the approval (ETA):
Installation performed by an appropriately qualified person

Note: Gross errors are not covered by prequalification tests !!!

Adhesive anchors - their reliable use in concrete

Conclusion

- The prequalification test conditions and evaluation criteria of adhesive anchors according to ACI 308 and ACI 355.X represent installation and service conditions in practice
- The design of adhesive anchors according to ACI 308 and ACI 318, App. D agrees with test results and considers the effect of sustained load with a reduction factor $\alpha_{sust}$
- The adhesive anchor installer training and certification program according to ACI 601 takes care of proper installation
- The provisions for adhesive anchors based on extensive research represent the state-of-art of fastening technique and yield reliable connections

Adhesive anchors - their reliable use in concrete

Reliable connections with adhesive anchor systems!

- ACI 308, ACI 355.X: Prequalified adhesive anchor
- ACI 308, ACI 318, App. D: Educated designer
- ACI 601 Certified Installer
- Reliable adhesive anchor connection
- ? Qualified Inspector

Adhesive anchors - their reliable use in concrete

Adhesive anchor installation - installer

The ACI 601 adhesive anchor installer training and certification program will consider

- the experience, limitations and capabilities of the installers
- the adhesive anchor relevant job site conditions
- the knowledge and understanding of the MPIIs
- the impact of deviations from the MPII
- the proper selection and use of the installation equipment and include
- a written and a performance exam

Adhesive anchors - their reliable use in concrete

Adhesive anchor installation - installer

0 2 04 06 08 10 0 %
30 % no cleaning
33 % brushing
37 % brushing and blowing

John Silva is Director of Codes and Approvals for Hilti, Inc. He is based in San Rafael, California. Mr. Silva holds a B.S. in Architectural Engineering from Cal Poly and an M.S. in Structural Engineering and Structural Mechanics from U.C. Berkeley.

Mr. Silva joined Hilti in 1994 to manage the Construction Technology Laboratory at the Hilti Technical Center in Schaan, Liechtenstein. He returned to the U.S. in 1998 to assume a variety of technical responsibilities related to regulation of anchoring products in North America. He is a member of ACI committees 355 and 408 (Bond), and the fib Special Applications Group on Anchorage to Concrete and BSSCC’s Provision Update Committee (Task Group for Non-Structural Elements). He is a licensed structural engineer in the state of California.

Draft Qualification and Design Provisions for Adhesive Anchors in Concrete

J. Silva
Appendix D, Anchoring to Concrete, first appeared in ACI 318 in 2002.

It addressed cast-in anchors and post-installed expansion and undercut anchors.

It did not address other anchor types, such as screw anchors, specialty inserts, or through-bolts.

It also did not address adhesive anchors, one of the most commonly employed anchor types in U.S. construction practice.

An effort is currently underway to include adhesive anchors in the 2011 code (supplement).

This work began in 2005.

The effort involves Committee 355 and Subcommittee B of the ACI 318 Main Committee.

If successful, it will result in both a qualification standard (ACI 355.X-YY) as well as design provisions in Appendix D specifically for adhesive anchors.

Issues:

Qualification parameters.
Design provisions.
Design for sustained tension.
Installation and design for overhead conditions.
Jobsite quality assurance.
Certification of installers.

Qualification of adhesive anchors has been a subject of intense interest over the past decade.

The basic objective is to establish the basic bond stress value(s) to be used in design.

It is also necessary to determine the sensitivity of the system to the (to some degree putative) influencing parameters.

Neither of these tasks is trivial.
Qualification of adhesive anchors under ACI 355.X-YY

Potential scope of assessment
- Embedment depth range 4d to 20d
- Characteristic adhesive bond strengths approaching 4,400 psi
- Concrete strengths 2,500 to 8,000 psi
- Diverse anchor element types (all-thread rod, rebar, inserts)

Challenge: Develop representative characteristic bond strengths for all permutations

Qualification of adhesive anchors under ACI 355.X-YY

Factors influencing the bond strength of adhesive anchors accounted for in ACI 355.X-YY
- Drilling method
- Hole cleaning
- Mixing
- Installation in wet concrete, water-filled holes, etc.
- Installation orientation
- Temperature
- Freeze/thaw
- Chemicals (alkalinity, sulfur)
- Sustained loading
- Cracked concrete
- Installation quality

Influence is product dependent: Prequalification is necessary
Issues:
Qualification parameters.
Design provisions.
Design for sustained tension.
Installation and design for overhead conditions.
Jobsite quality assurance.
Certification of installers.

Design model as implemented in CB100:

\[ N_{bd} = \frac{A_{ac}}{A_{cco}} \frac{N_{c,c}}{N_{ed, N_{c,c}} N_{ed, N_{c,c}} N_{ed, N_{c,c}} N_{ed, N_{c,c}}} \leq \frac{A_{ac}}{A_{cco}} \frac{N_{c,c}}{N_{ed, N_{c,c}} N_{ed, N_{c,c}} N_{ed, N_{c,c}} N_{ed, N_{c,c}}} N_{b} \]

bond failure  
concrete breakout

With respect to concrete failure modes in tension: The calculated bond strength cannot exceed the concrete breakout strength...

Issues:
Qualification parameters.
Design provisions.
Design for sustained tension.
Installation and design for overhead conditions.
Jobsite quality assurance.
Certification of installers.
Design for sustained tension involves a separate check on the bond strength as follows:

\[ 0.55 \phi N_{up} \geq N_{ut,\text{sustained}} \]

This check is made on the anchor carrying the highest sustained tension load.

Issues:
- Qualification parameters.
- Design provisions.
- Design for sustained tension.
- Installation and design for overhead conditions.
- Jobsite quality assurance.
- Certification of installers.

Regarding overhead and horizontal installation of adhesive anchors to resist sustained loads:

1. All systems to be used for overhead and horizontal installation must be qualified for these installation orientations.
2. Installers must be certified.
3. Continuous special inspection is required.

Qualification of adhesive anchors under ACI308/ACI 355.X-YY

- Special inspection
  - special inspector is present during anchor installation to verify diameter, embedment, adherence to manufacturer’s installation instructions
- Proof loading
  - tension testing (usually confined) of a percentage of the installed anchors to a fraction of the ultimate bond strength or anchor element yield strength, usually with visual tracking of displacement.
### Issues:

- Qualification parameters.
- Design provisions.
- Design for sustained tension.
- Installation and design for overhead conditions.
- Jobsite quality assurance.
- Certification of installers.

**ACI/CIRSI Adhesive Anchor Installer Certification**

* (in development)

1. Written exam (40-50 multiple choice).
2. Performance exam downhole install (all steps, in concrete).
3. Performance exam overhead install (blind acrylic tube injection)

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**Andra Hörmann-Gast** has been performing consulting services for the ICC Evaluation Service since 2008. Previously, she worked in the Anchorage and Fastening Division of the German Institute for Building Technology (DIBt) in Berlin for 8 years. During that time, she was responsible for many different national and European Approval procedures, including adhesive anchors in masonry and concrete. Prior to joining the DIBt, she worked in a bridge design office. She holds a Master’s degree in civil engineering from Brandenburg Technical University, Germany, and a Master’s degree in bridge engineering from the University of Surrey, England.

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**ADHESIVE ANCHORS ACROSS BORDERS:**

A Comparison of Testing, Qualification, and Design between the U.S. and Europe

Jake Olsen
Andra Hörmann-Gast

ACI Spring Convention, Chicago – “What About Adhesive Anchors?” March 24, 2010
Organizations developing standards, codes and guidelines

European Organisation for Technical Approvals (EOTA)

American Concrete Institute

International Code Council (ICC)

EOTA – Evaluation Service

Organizations developing standards, codes and guidelines

• Safety relevant applications: ETA for adhesive anchors
• EOTA approval bodies; 27 European states
• ETAG 001
• Qualification of adhesive anchors (ACI 355.X)
• ACI 318, Appendix D: Design provisions for anchors (commentary: Adhesive anchors are mentioned)
• Committees 318, 318-0B, 355, 601-A0
• IBC / IRC: Adhesive Anchors are alternative materials validated by research reports from approved sources
  • Code compliance
  • Acceptance Criteria, ESRs
  • ACI 308

• Committees 318, 318-0B, 355, 601-A0
• IBC / IRC: Adhesive Anchors are alternative materials validated by research reports from approved sources

Approvals and Evaluation Reports

ETA: European Technical Approval under ETAG 001

Evaluation Reports under ACI 355.X

ESR: Evaluation Service Reports under ACI 308

Similarities / Differences

• no open process
• EOTA working groups
• reporting to the European Commission (E.U.)
• ETAs by EOTA have status of law

• open process, open hearings
• advisory documents
• documents no legal standing until adopted by legal jurisdictions (AHJs)

Approvals and Evaluation Reports

• no European codes for anchors available
• ETAG 001 only path to allow adhesive anchor use for safety-relevant applications
• EOTA process (circulation of Evaluation report and ETA draft)
• 275 ETAs for adhesive anchors to date (March 2010)

• ACI 355.X and ACI 318, Appendix D under review
• ESRs according to ACI 308 for evidence of code compliance
• 8 ESRs for adhesive anchors to date (March 2010)

Approved by all European approval bodies
• standard format
• level of authority as a code

• Eval. Reports under ACI 355.X show code compliance, issued without circulation, i.e. maybe issued by one PE
• ESRs according to ACI 308: evidence for use of adhesive anchors as code alternatives
• no legal standing unless accepted by AHJ
Qualification Procedures

Similarities / Differences
- Identification, Reference, Reliability, Service-condition tests
- Test program, flexible, arranged between manufacturer/approval body
- New research: Comprehension Document, Progress File
- New research: ICC-ES Hearing process
- New research: ACI Committee 355, TAC (Technical Advisory Group), public comments

Manufacturing requirements and quality control

Similarities / Differences
- Tasks manufacturer/approval body
- Marking
- Inspections twice yearly (or less)
- Approved quality assurance program
- Quarterly inspections
- Inspection agency accredited by IAS (or recognized through MRA)
- ACI Acceptance Criterias for quality documentation

Design requirements

- Four Technical Reports (torque-controlled adhesive anchors, evaluation for resistance to fire, post-installed rebar, design)
- ACI 355.X under development
- ACI 308 (drafted by CAMA (2006))
- ASTM standards (referenced in ACI 355 and ACI 308)

Scope

<table>
<thead>
<tr>
<th></th>
<th>ETAG 001</th>
<th>ACI 308</th>
<th>ACI 355.X</th>
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<tbody>
<tr>
<td>Approval body</td>
<td>NO</td>
<td>Approved body may reduce scope according to experience</td>
<td>YES</td>
</tr>
<tr>
<td>Optional qualification for rebar resistance?</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
</tr>
<tr>
<td>Includes torque controlled anchors?</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
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<tr>
<td>Procedure for evaluating rebar resistance?</td>
<td>NO</td>
<td>YES</td>
<td>NO</td>
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<tr>
<td>Testing</td>
<td></td>
<td></td>
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<tr>
<td>Testing on product randomly sampled by and independent party?</td>
<td>NO</td>
<td>YES</td>
<td>YES</td>
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<td>Testing in wet concrete and under freeze/thaw conditions mandatory?</td>
<td>NO</td>
<td>NO (optional)</td>
<td>YES</td>
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<tr>
<td>Minimum flexing temperature for sustained load test</td>
<td>68°F (20°C)</td>
<td>77°F (25°C)</td>
<td>68°F (20°C)</td>
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<td>Tests required to determine the effects of regional concrete variations</td>
<td>YES</td>
<td>via round-robin tests</td>
<td>via round-robin tests</td>
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<tr>
<td>Evaluation</td>
<td></td>
<td></td>
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<tr>
<td>Adhesive anchor must meet a minimum bond strength to be approved?</td>
<td>NO</td>
<td>NO</td>
<td>YES</td>
</tr>
<tr>
<td>Different design methods are included in the standard/guide?</td>
<td>YES</td>
<td>NO</td>
<td>NO</td>
</tr>
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</table>
Design requirements

Similarities / Differences

• partial safety factor concept, gamma (γ)
• ultimate limit state, serviceability limit state
• no reductions for overhead applications or sustained loads

• ACI 318, still under discussion, reduction factor for sustained loads, certified installer program

• strength design concept, phi (φ)
• ICC-ES AC318:0.75 reduction factor for sustained loads

Installation and jobsite quality control

• Installation in accordance with ETA, by an appropriately qualified person, supervision by the person responsible for technical matters on site
• No inspection program

• ACI 318: precondition for overhead: installer certification program

• Inspector qualification
• Special inspection according to IBC
• Periodic special inspection
• Continuous special inspection (overhead + sustained loading)
• Proof loading program

Summary

Large degree of conformity in testing, assessment, and design requirements.

Differences remain (e.g. seismic qualification, overhead installation, sustained loading, jobsite quality control).

Efforts to resolve ongoing.

Integration of state of the art advances.

Involvement across borders.

Where to get more information ...

www.eota.eu

www.concrete.org

www.icc-safe.org

www.icc-es.org

Related Documents

Anchorage to Concrete

• 355.2-07: Qualification of Post-Installed Mechanical Anchors in Concrete & Commentary
• 349.2R-07: Guide to the Concrete Capacity Design (CCD) Method - Embedment Design Examples
• 503.5R-92: Guide for the Selection of Polymer Adhesives in Concrete (Reapproved 2003)
• SP-103: Anchorage to Concrete
• SP-130: Anchors in Concrete--Design and Behavior
• 318-08: Building Code Requirements for Structural Concrete and Commentary

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