Best practice specification, design and installation for post-installed anchors in safety-critical applications

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www.aefac.org.au
KEY TAKE-AWAY POINTS

- TS 101 is for safety-critical applications only
- Concrete is assumed to be cracked unless proven otherwise
- Not all chemical anchors are the same, particularly under sustained loading applications – not all chemicals are suitable for sustained loading applications.
  - For e.g. in uncracked concrete, a polyester may have bond strength in the range of 5 – 9 MPa while an epoxy may have bond strength in the range of 10 – 15 MPa

- For quality assurance of safety critical applications, require:
  - Product prequalification
  - Design as per TS 101
  - Installation by qualified installers
OUTLINE

- Australian Engineered Fasteners and Anchors Council
- Anchor types and safety-critical applications
- Prequalification
- Design methodology
- Installation
- Case study
- Summary & acknowledgements
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Guidelines for the specification of anchors
For Designers

Training & certification for installers of anchors
For Contractors

Minimum performance & standard specification
For Manufacturers

Guideline for field testing & certification of anchors
For Field Engineers

Research & Development
For anchor industry

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SAFETY-CRITICAL APPLICATIONS & TYPES OF ANCHORS
Fastening for safety-critical applications

A fastening whose failure may result in collapse or partial collapse of the structure, endanger human life and/or cause considerable economic loss.
Applications

Nonstructural
- Facades
- Suspended ceilings
- Heating & ventilation
- Pipelines
- Mechanical equip.
- Etc.

Structural
- Structural connections
- Strengthening

Eligehausen (University of Stuttgart)
- **Types of anchors:**

  Post installed anchors

  Cast in anchors
Post-installed applications: steel to concrete connections
Post-installed applications: concrete to concrete connections
CAST IN PLACE ANCHORS
WHAT CAN GO WRONG WITH ANCHORS?

Street awning collapse in Queensland

1 fatality, 5 injuries

Source: Workplace Health and Safety Queensland
What Can Go Wrong with Anchors?

Photograph taken following incident showing roof hangers pulled away from tunnel roof.

Source: Brady, S., “Interstate 90 Connector Tunnel ceiling collapse” The Structural Engineer, April 2013

Boston Big Dig Tunnel, 2006

What Can Go Wrong with Anchors?

Typical chemical anchor and roof hanger plate assembly.

Three of the 20 failed anchors taken from the site of the incident illustrating defects.

SAFETY-CRITICAL APPLICATIONS

Three critical elements to achieve quality assurance

1. PREQUALIFICATION → Products independently assessed to be “fit for purpose”

2. DESIGN → Rigorous assessment to design for critical mode of failure

3. INSTALLATION → Informed and competent installer with appropriate supervision and experience
PREQUALIFICATION

SA TS101:2015 APPENDIX B
PREQUALIFICATION

- **Identification tests** – is product fully traceable and does it meet product specifications?
- **Suitability tests** – is the product suitable for its intended application?
- **Admissible service condition tests** – will the product perform for its service life?
PREQUALIFICATION IN TS101

Two approaches for prequalification:

1. **Testing and assessment in accordance with Appendix B**
   Testing in accordance with ETAG001 parts 1 to 5 or EAD as applicable and assessment as outlined in Appendix B

Or

2. **European Technical Assessment (ETA)**
   A current ETA satisfies the relevant testing and assessment requirements as outlined in Appendix B
Three critical elements to achieve **quality assurance**

1. **PREQUALIFICATION** → Products independently assessed to be “fit for purpose”

2. **DESIGN** → Rigorous assessment to design for critical mode of failure

3. **INSTALLATION** → Informed and competent installer with appropriate supervision and experience
SA TS 101—2015

“Design of post-installed and cast-in fastenings for use in concrete”
Deemed-to-satisfy provisions

- Primary reference in 2016 NCC:
  - NCC Volume One – Clause B1.4(b)(iii)
  - NCC Volume Two – Clause 3.11.6(f)(iii)
SA TS 101—2015

2016 NCC

SA TS 101 (Deem-to-Satisfy)

ALTERNATIVE SOLUTION

PREQUALIFICATION (APPENDIX B)

AEFAC Installer Certification Program (RECOMMENDED)

TEST & ASSESS (APPENDIX B) (ETAG & EAD)

ETA
Overview

- Based on European guidelines
- Compatible with products prequalified through Appendix B

Scope – safety-critical fasteners

- **Post-installed**
  - Mechanical anchors
  - Chemical anchors

- **Cast-in**
  - Anchor channel
SA TS 101—2015

Exclusions

- Design for exposure to fire, durability and seismic actions
- Design of fixtures
- Design of fasteners for lifting, transport and erection (brace inserts, lifting inserts, etc.)
- Headed fasteners
- Ferrules
- Reinforcement for development length considerations
- Headed reinforcement
- Anchorage for prestressing strands
Determination of forces acting on fasteners

- Load sharing among fasteners
- Eccentricity in a fastener group
- Influence of edges
- Influence of a lever arm
- Influence of fixture plate
- Load resisted by supplementary reinforcement (if present)
Permissible configurations of fastenings:

a) Configurations of fasteners close to an edge \( (c_i < \max(10h_{ef}, 60d_{nom})) \), tension only

b) Configurations of fasteners remote from edges \( (c_i \geq \max(10h_{ef}, 60d_{nom})) \), all load directions

c) Configurations of fasteners close to an edge \( (c_i < \max(10h_{ef}, 60d_{nom})) \), all load directions
TS 101: CRACKED CONCRETE

- Limited to maximum crack width of 0.3 mm
- Concrete assumed to be CRACKED in design unless proven otherwise.
- Note: Not all products can be used in cracked concrete!!
SA TS 101—2015

**Shear**

- Fracture (No Lever Arm)
- Bending (Lever Arm)
- Edge Failure
- Pryout Failure
- Anchor Failure
- Anchor/Channel Failure
- Lip Flexure Failure
- Edge Failure
- Pryout Failure

(a) Fracture
(b) Anchorage

Supplementary Reo.
SA TS 101—2015: Shear Loads Distribution Close to an Edge

Shear load parallel to edge

Shear load perpendicular to edge (only 2 fasteners closest to edge considered)
SA TS 101—2015

- Steel failure – bolt failure
- Steel failure – anchor channel modes
- Other failure modes
- Supplementary reinforcement
Example: Concrete cone failure mode (tension)

Inverted rectilinear pyramid

Cross-section

Plan view

\[ N_{Rk,c} = N_{Rk,c}^0 \left( \frac{A_{c,N}}{A_{c,N}^0} \right) \psi_{s,N} \psi_{re,N} \psi_{ec,N} \psi_{M,N} \]

\[ N_{Rk,c}^0 = \text{characteristic concrete cone strength (no spacing effects, edge effects, etc.)} = k_g \sqrt{f'_c h_e}^{1.5} \]

\( \left( \frac{A_{c,N}}{A_{c,N}^0} \right) \) = adjustment for effects of fastener spacing and edge effects (can the full inverted rectilinear pyramid cone form?)

\( \psi_{s,N} \) = factor accounting for disturbance of stresses in concrete due to an edge

\( \psi_{re,N} \) = factor accounting for a dense layer of reinforcement in concrete

\( \psi_{ec,N} \) = factor accounting for different tension loads on fasteners in a group subjected to eccentric loading

\( \psi_{M,N} \) = factor accounting for the influence of a compression force between the fixture and concrete when a bending moment is present

NB: Still need to consider other potential modes of failure to determine decisive failure mode!
Software

- Freely available from reputable manufacturers
- Rapidly solve complex designs (minutes vs. hours/days!)
- Include prequalified products (i.e. ETA)
- Compatible with TS 101 (with conversion)
SA TS 101—2015: DESIGN SOFTWARE

- List of software that design to SA TS 101 / ETAG
  - Ramset – iExpert™
  - Hilti - PROFIS
  - Wurth – Technical Software
  - Powers – Design Assist
  - Simpson Strong Tie – Anchor Designer

Free download on website
Refer to AEFAC’s website [www.aefac.org.au](http://www.aefac.org.au) for FREQUENTLY ASKED QUESTIONS on SA TS 101.
Three critical elements to achieve quality assurance

1. Prequalification
   - Products independently assessed to be “fit for purpose”

2. Design
   - Rigorous assessment to design for critical mode of failure

3. Installation
   - Informed and competent installer with appropriate supervision and experience
AEFAC Installer Certification Program
AEFAC Installer Certification Program

“The best product is only as good as its installation”
Correct installation is imperative to ensure the designer’s intent is met

- Until now, performed on an ad-hoc basis – job dependent, product specific
- Reasonable errors acceptable, gross errors dangerous
- Combination of appropriate training and supervision critical
- Clear need for a program to provide:
  - Written and practical test
  - How to correctly drill
  - How to correctly prepare a hole
  - Understanding anchor systems
  - Understanding risks of errors
<table>
<thead>
<tr>
<th>Element</th>
<th>Europe†</th>
<th>U.S.‡</th>
</tr>
</thead>
<tbody>
<tr>
<td>Training</td>
<td></td>
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<td>- theoretical</td>
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<tr>
<td>- practical</td>
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<tr>
<td>- vertical-down</td>
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<tr>
<td>- overhead</td>
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<tr>
<td>Exam</td>
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<td>- theoretical</td>
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<tr>
<td>- practical</td>
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<tr>
<td>- independent assessment</td>
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<td>•</td>
</tr>
<tr>
<td>- re-certification (written and practical)</td>
<td>2 – 3 years</td>
<td>5 years</td>
</tr>
</tbody>
</table>

† Performed on a Member State basis, currently only mandatory in Germany for post-installed rebar connections.
‡ ACI 318-14: “Installer certification and inspection requirements for horizontal and upwardly inclined adhesive anchors subjected to sustained tension loading shall be in accordance with 17.8.2.2 through 17.8.2.4.” (Cl. 17.2.5)
Importance of hole cleanliness

Drill dust will prevent proper bonding -> Strength reduction!

Well-cleaned

Poorly cleaned

Courtesy of IWB, University of Stuttgart
Sensitivity to cleaning method

Drill dust will prevent proper bonding -> Strength reduction!

This chart is product-specific only!

Method of hole cleaning

1 – 2xblowing, 2xbrushing, 2xblowing
2 – 1xblowing, 1xbrushing, 1xblowing
3 – 2xblowing
4 – No cleaning (drilling machine retracted 3 times)
AEFAC Installer Certification Program

Training
Face to face training, Installer Training Manual

Written examination

Practical examination
Part 1: Vertical down installation
Part 2: Overhead injection

Certification awarded

Recertification period
Initial: Three years
Additional: Every five years

*This program is based on the US ACI-CRSI Adhesive Anchor Installer Program modified for Australian practice
Important note:
“By completing certification, you have demonstrated that you understood the risks involved in poor installation practices”
Abide to the AEFAC Installer Code of Conduct

Failure to comply after certification awarded
✓ Certification status revoked
✓ Potential legal implications!

Certified Installer Card awarded & registration on AEFAC’s website
AEFAC INSTALLER CERTIFICATION PROGRAM
AEFAC INSTALLER CERTIFICATION PROGRAM
INSTALLER CERTIFICATION PROGRAM – OVERHEAD INJECTION
INSTALLER CERTIFICATION PROGRAM – OVERHEAD INJECTION
But I’ve been doing it *this way* for years!
1 SCOPE
This Technical note provides recommendations for the information to be included on engineering drawings for the specification of safety critical fastenings for use in concrete.

Note: The advice provided in this document is of a general nature and should not be considered a substitute for manufacturer’s installation instructions or technical advice from the manufacturer/supplier.

2 GENERAL
A complete and accurate specification of a fastener fixed into concrete requires the following to be addressed:

1. Sufficient information included to ensure that the product designed is the product that is installed (refer to Section 6).
2. Installation of the fasteners is performed by a suitably experienced and qualified installer under appropriate supervision (refer to Section 5).
3. A suitable change management procedure is followed if the installation cannot proceed as intended (refer to Section 7).

Fasteners are to be treated as a system including fastener products, hole preparation and installation techniques. The following points should be considered:

- Incorrect installation such as poor hole drilling, may reduce fastener performance and prevent the fastener from functioning as intended.
- A complete and accurate specification is necessary to ensure that the correct product is procured and installed correctly.

3 PREQUALIFICATION
Fasteners for use in concrete in safety-critical applications should have a prequalification that is complete with the design provisions stipulated in AS3600–2009 and that is appropriate for the given application.

4 PRODUCT INFORMATION
The information listed in the specification should be sufficiently detailed to clearly define the product and its installation as assumed in the design. It may be possible to install a similar product only if it has been approved by the responsible engineer.

4.1 Recommendation for the minimum information to be included in the specification for different types of fasteners is included in the appendices of this Technical Note. However, the manufacturer’s installation instructions should always be consulted for a complete list of items to be included in the specification.

A.1.1 Chemical fasteners

- Chemical fasteners are sensitive to poor installation methods.

Minimum information to be specified
Always refer to manufacturer’s installation instructions for a complete list of items to be included in the specification.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Manufacturer’s name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anchor rod</td>
<td></td>
</tr>
<tr>
<td>Type</td>
<td>(E.g. Threaded rod)</td>
</tr>
<tr>
<td>Diameter</td>
<td>(E.g. M12)</td>
</tr>
<tr>
<td>Length (mm)</td>
<td>(E.g. 200mm)</td>
</tr>
<tr>
<td>Finish/Coating</td>
<td>(E.g. Galvanised)</td>
</tr>
<tr>
<td>Strength Grade</td>
<td>(E.g. Class 8.8)</td>
</tr>
<tr>
<td>Depth of embedment (mm)</td>
<td>(E.g. 110mm)</td>
</tr>
<tr>
<td>Drill hole</td>
<td></td>
</tr>
<tr>
<td>Diameter (mm)</td>
<td>(E.g. 14mm)</td>
</tr>
<tr>
<td>Depth (mm)</td>
<td>(E.g. 110mm)</td>
</tr>
<tr>
<td>Drill type</td>
<td>(E.g. Carbide-tipped)</td>
</tr>
<tr>
<td>Max tightening torque (Nm)</td>
<td>If applicable</td>
</tr>
</tbody>
</table>

Example text for specification
- The chemical product shall be a (manufacturer name, product name). The anchor rod shall be a M12 x 200 threaded rod, galvanised, steel grade 8.8, installed in a 14mm diameter hole with a 110 mm depth and tightened to a maximum 100 Nm torque using a calibrated torque wrench.
- Cleaning accessories prescribed by the manufacturer’s installation instructions shall be used.
Proposed notes for contract drawings

5 INSTALLATION

The installer should be suitably competent for the fastener installation that may be demonstrated by being a current AEFAC certified installer, or an installer with the appropriate training from the manufacturer/supplier for the specified product being installed.

The installation should follow the manufacturer’s installation instructions and any additional information specified by the design engineer.

The installation depth of the fastener should be shown on the drawing.

Recommended text for specification

- All fasteners must be installed in accordance with the manufacturer’s installation instructions that may be supplemented by information specified by the design engineer.

- Installation should be performed by an AEFAC certified installer or by a person trained by the manufacturer/supplier of the specified product.
Anchor industry is **safety-critical**.

Anchor failures should not happen – they do!

AEFAC has created a body of knowledge and expertise to introduce governance to the Australian anchor industry.

Satisfactory anchor performance is achieved from: i) appropriate product prequalification, ii) robust design, and iii) correct installation.

TS 101 provides a consistent and robust approach to anchor design based on best practice.

The AEFAC Installer Certification Program has been developed to equip installers with the skill to ensure that anchors are installed as intended.
Website

- Overview of AEFAC
- AEFAC members
- Education events
- Technical Notes
- Sample Specifications
- Installer Certification
- TS 101: FAQ
- Links to resources

www.aefac.org.au
SUMMARY & ACKNOWLEDGEMENTS

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