Deemed-to-satisfy provisions for the design of fastenings to concrete in Australia

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DISCLAIMER

These seminar notes have been prepared for general information only and are not an exhaustive statement of all relevant information on the topic. This guidance must not be regarded as a substitute for technical advice provided by a suitably qualified engineer.

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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

Part 1
- Australian Engineered Fasteners and Anchors Council
- Types of anchors and safety-critical applications
- Prequalification
- Design methodology

Part 2
- Installation
- Case study
- Summary & acknowledgements
AUSTRALIAN ENGINEERED FASTENERS AND ANCHORS COUNCIL

Guidelines for the specification of anchors
For Designers

Trainee & 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

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

Elgehausen (University of Stuttgart)
Types of anchors:

- Post installed anchors
- Cast in anchors

**Types of Post Installed Anchors**

- **Mechanical Anchors**
  - Torque-controlled expansion anchors
  - Through-bolt
  - Thick-walled sleeve
  - Thin-walled sleeve
  - Shield-type
  - Undercut
  - Self-undercut
  - Screw
  - Deformation-controlled
    - "Drop-in"

Note: Very sensitive to drill hole diameter!

Source: BS8539
### Types of Post Installed Anchors

- **Chemical Anchors**

#### Bonded

- Threaded rod
- Internal thread
- Torque-controlled
- Rebar

*Note: Hole cleanliness very important!*

### Why Are Chemical Anchors Widely Used?

- Potential for smaller edge & spacing requirements
Post-installed applications: steel to concrete connections

Post-installed applications: concrete to concrete connections
CAST IN PLACE ANCHORS

Curtain wall glass element

Curtain wall bracket (system Gartner)

HTA channel

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

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

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**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
SAFETY-CRITICAL ANCHORS

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)
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

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
SA TS 101—2015

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)

Limitations
- Fasteners min. diameter of 6mm, no max. for tension loading, max. of 60mm diameter for shear loading
- Fasteners material tensile strength, $f_u \leq 1000\text{MPa}$
- $40\text{mm} \leq h_{ef} \leq 20d_{nom}$ for chemical fasteners ($h_{ef} –$ effective embedment depth, $d_{nom} –$ outside diameter of fastener)
- Concrete $f'_c$ for design purposes shall not exceed 60MPa
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

TENSION

ANCHOR BOLT FRACTURE
CHANNEL LIP FRACTURE
CHANNEL FLEXURE
ANCHOR/CHANNEL CONNECTION
SUPPLEMENTARY REINFORCEMENT – FRACTURE
SUPPLEMENTARY REINFORCEMENT – ANCHORAGE FAILURE
SA TS 101—2015

**Shear**

- Fracture (No Lever Arm)
- Bending (Lever Arm)
- Edge Failure
- Pryout Failure
- (a) Fracture Supplementary Req.
- (b) Anchorage Supplementary Req.

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)

\[ N_{Rd,v} = N_{Rd,v}^0 \left( \frac{A_{h,v}}{A_{c,v}} \right) \psi_{c,v} \psi_{M,N} \]

- \( N_{Rd,v}^0 \) = characteristic concrete cone strength (no spacing effects, edge effects, etc.)
- \( A_{h,v} \) = \( h_v \sqrt{f_v \cdot h_{v,5}} \)
- \( A_{c,v} \) = adjustment for effects of fastener spacing and edge effects (can the full inverted rectilinear pyramid cone form?)
- \( \psi_{c,v} \) = factor accounting for disturbance of stresses in concrete due to an edge
- \( \psi_{M,N} \) = factor accounting for a dense layer of reinforcement in concrete
- \( \psi_{e,v} \) = 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!
SA TS 101—2015: DESIGN METHODOLOGY

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
SA TS 101—2015: FAO

- Refer to AEFAC’s website [www.aefac.org.au](http://www.aefac.org.au) for FREQUENTLY ASKED QUESTIONS on SA TS 101

SAFETY-CRITICAL ANCHORS

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

“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
**Importance of hole cleanliness**

Drill dust will prevent proper bonding -> Strength reduction!

Well-cleaned

Poorly cleaned

Courtesy of IWB, University of Stuttgart
AEFAC INSTALLER CERTIFICATION PROGRAM

Sensitivity to cleaning method

Drill dust will prevent proper bonding -> Strength reduction!

Method of hole cleaning

1 – 2x blowing, 2x brushing, 2x blowing
2 – 1x blowing, 1x brushing, 1x blowing
3 – 2x blowing
4 – No cleaning (drilling machine retracted 3 times)

AEFAC INSTALLER CERTIFICATION PROGRAM

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

INSTALLER CERTIFICATION PROGRAM – OVERHEAD INJECTION
But I’ve been doing it this way for years!
AEFAC TECHNICAL NOTE – ENGINEERING GENERAL NOTES

HTTP://WWW.AEFAC.ORG.AU/DOCUMENTS/AEFAC-TN-ENG-GEN-NOTES.PDF

AEFAC TECHNICAL NOTE – ENGINEERING GENERAL NOTES

www.aefac.org.au/resources

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 24mm 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.
**AEFAC ENGINEERING GENERAL NOTES**

**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.

**CASE STUDY**
CASE STUDY

- 11.20pm, August 13, 2011, 190 feet (58 m) canopy-fence collapsed onto the 20 lane Interstate Highway 75/85

Nobody was injured, no vehicles damaged

Canopy-fence collapsed onto 20-lane Interstate Highway 75/85

Investigation found:

- Bridge opened seven years earlier (2004)
- Anchors were subjected to **sustained load** that was substantially lower than (approx. ¼ of) the design service load
- **Voids** 1 – 1.5 inches in length detected at rear of holes
- **Wet epoxy** extracted from holes (7 years after installation)
- Laboratory studies revealed **different material composition** in different areas and hardener-rich and resin-rich areas
- Adhesive was susceptible to **creep**
CASE STUDY

Bent anchor rod, some that is smooth – without thread

Epoxy removed from hole seven years after installation.

Typical column-cantilever assembly detail.


SUMMARY & ACKNOWLEDGEMENTS

- 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
SUMMARY & ACKNOWLEDGEMENTS

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

www.aefac.org.au