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

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Swinburne University of Technology

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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.

For further information contact Jessey Lee: aefac@aefac.org.au

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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

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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

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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

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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

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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.

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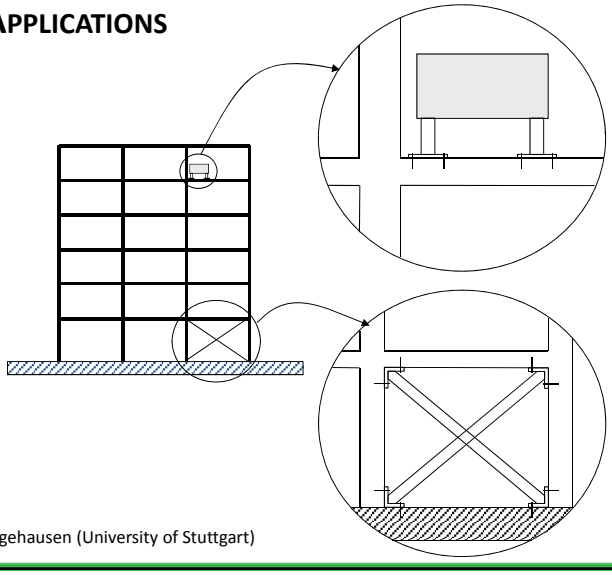
APPLICATIONS



Nonstructural

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

Structural

- Structural connections
- Strengthening

Eligehausen (University of Stuttgart)

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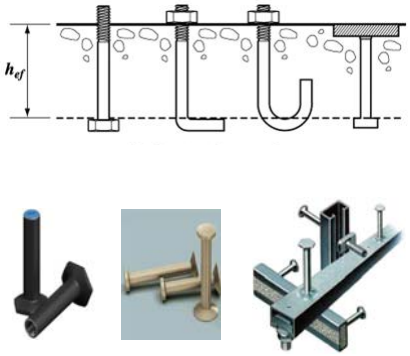
- *Types of anchors:*

Post installed anchors

Cast in anchors



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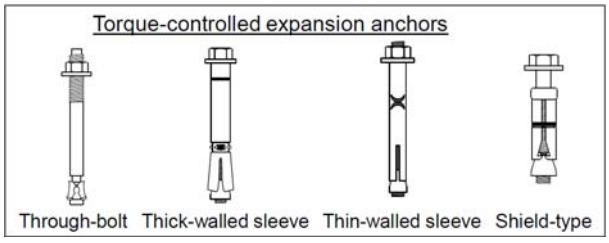
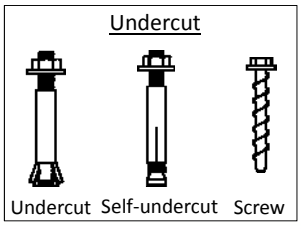
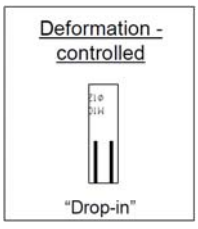
TYPES OF POST INSTALLED ANCHORS

- *Mechanical Anchors*







Note: Very sensitive to drill hole diameter!

Source:BS8539

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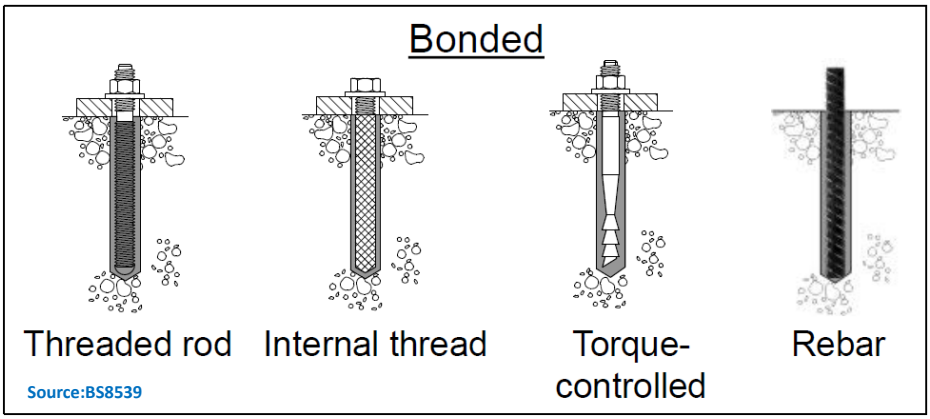
TYPES OF POST INSTALLED ANCHORS

- *Chemical Anchors*



Note: Hole cleanliness very important!

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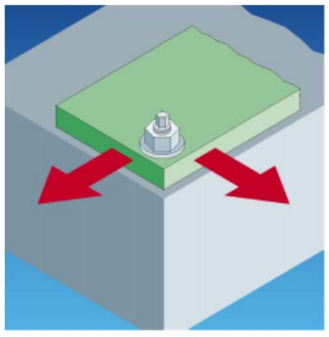
WHY ARE CHEMICAL ANCHORS WIDELY USED?

- Potential for smaller edge & spacing requirements



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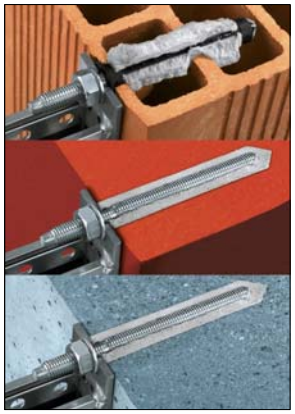
Post-installed applications: steel to concrete connections



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Post-installed applications: concrete to concrete connections

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CAST IN PLACE ANCHORS

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WHAT CAN GO WRONG WITH ANCHORS?

Street awning collapse in Queensland

1 fatality, 5 injuries

Source: Workplace Health and Safety Queensland

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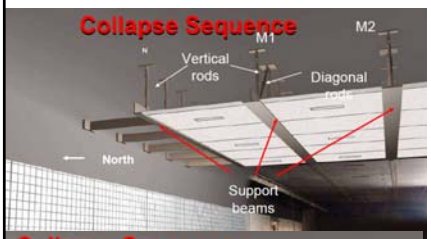
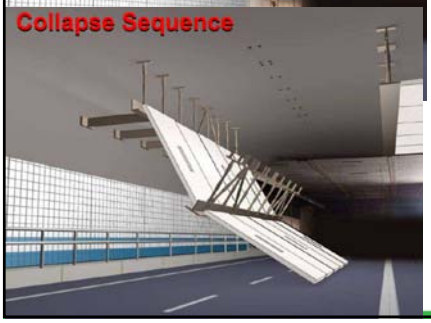
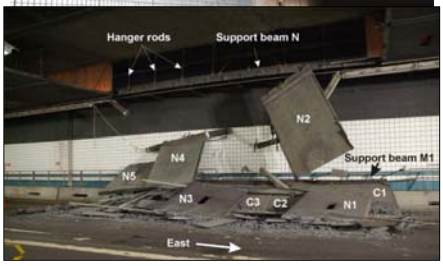
WHAT CAN GO WRONG WITH ANCHORS?



Boston Big Dig Tunnel, 2006





Source: NTSB (2007) Highway Accident Report, "Ceiling collapse in the Interstate 90 Connector Tunnel, Boston, Massachusetts, July 10, 2006"

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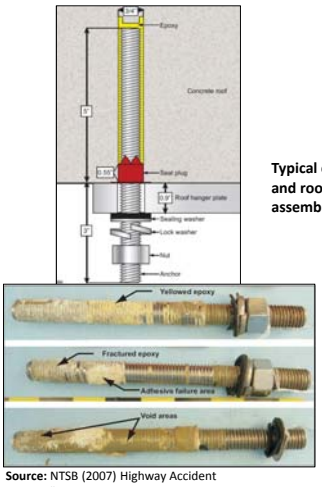
WHAT CAN GO WRONG WITH ANCHORS?

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



Typical chemical anchor and roof hanger plate assembly.

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

Source: NTSB (2007) Highway Accident Report, "Ceiling collapse in the Interstate 90 Connector Tunnel, Boston, Massachusetts, July 10, 2006"

Boston Big Dig Tunnel, 2006

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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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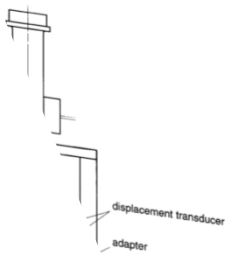
PREQUALIFICATION



SA TS101:2015 APPENDIX B

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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?

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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

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SAFETY-CRITICAL ANCHORS

Three critical elements to achieve quality assurance

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

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"DESIGN OF POST-INSTALLED AND CAST-IN FASTENINGS FOR USE IN CONCRETE"

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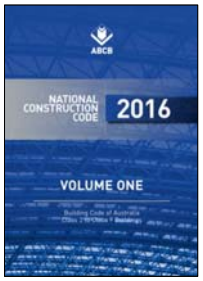
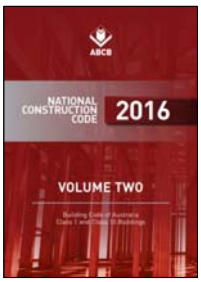
Deemed-to-satisfy provisions

- Primary reference in 2016 NCC:
  - ✓ NCC Volume One – Clause B1.4(b)(iii)
  - ✓ NCC Volume Two – Clause 3.11.6(f)(iii)





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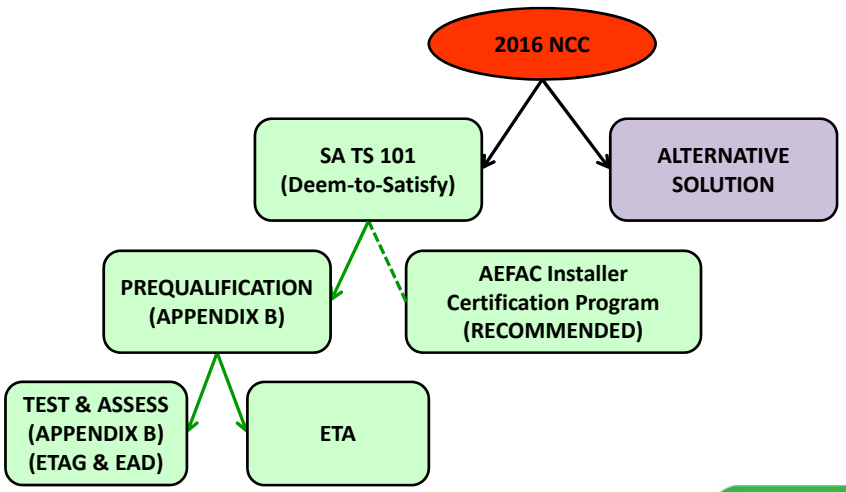

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Overview

- 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

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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

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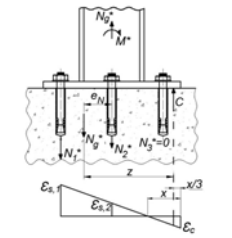
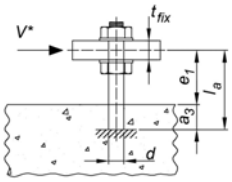
Determination of forces acting on fasteners

- 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)





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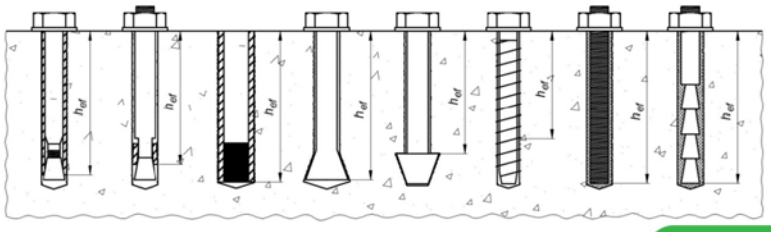
Limitations

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



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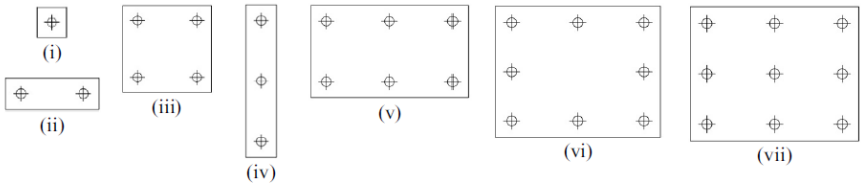
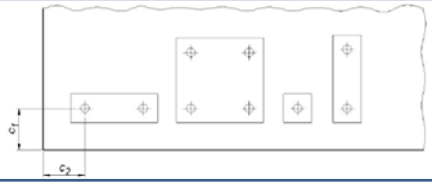
Permissible configurations of fastenings:



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

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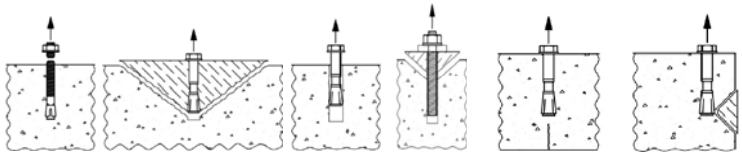
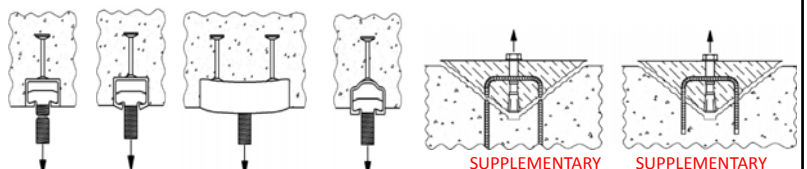
TENSION





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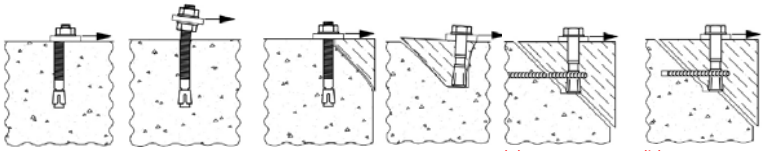
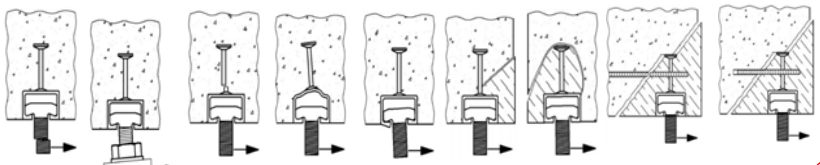
SHEAR



FRACTURE (NO LEVER ARM) | BENDING (LEVER ARM) | EDGE FAILURE | PRYOUT FAILURE | (a) FRACTURE | (b) ANCHORAGE

SUPPLEMENTARY REO.



FRACTURE (NO LEVER ARM) | BENDING (LEVER ARM) | ANCHOR FRACTURE | ANCHOR/ CHANNEL CONNECT. | LIP FLEXURE | EDGE FAILURE | PRYOUT FAILURE | (a) FRACTURE | (b) ANCHORAGE

SUPPLEMENTARY REO.

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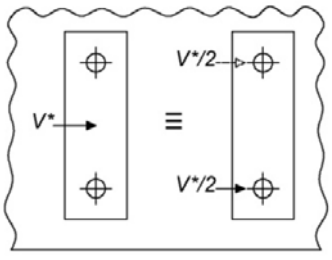
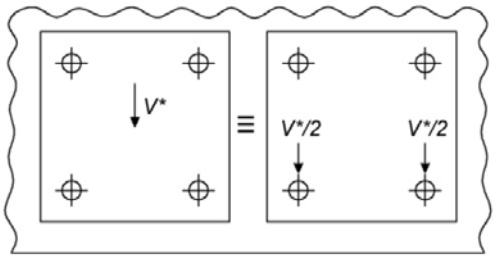
SA TS 101—2015: SHEAR LOADS DISTRIBUTION CLOSE TO AN EDGE



Shear load parallel to edge



Shear load perpendicular to edge (only 2 fasteners closest to edge considered)

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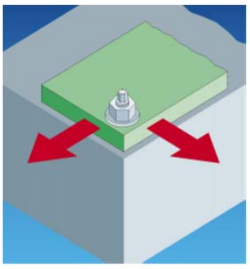
COMBINED

- Steel failure – bolt failure
- Steel failure – anchor channel modes
- Other failure modes
- Supplementary reinforcement



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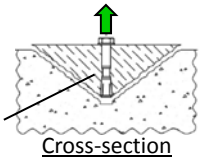
SA TS 101—2015 : DESIGN METHODOLOGY

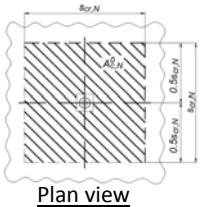
Example: Concrete cone failure mode (tension)

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

Inverted rectilinear pyramid



Cross-section



Plan view

$N^0_{Rk,c}$ = characteristic concrete cone strength (no spacing effects, edge effects, etc.)

$= k_9\sqrt{f'_c}\,h_{ef}^{1.5}$

$\left(\frac{A_{c,N}}{A^0_{c,N}}\right)$ = 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!

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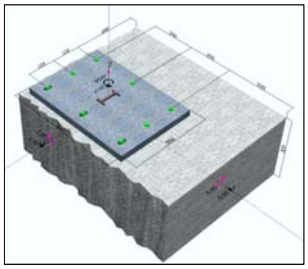
SA TS 101—2015 : DESIGN METHODOLOGY

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)



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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

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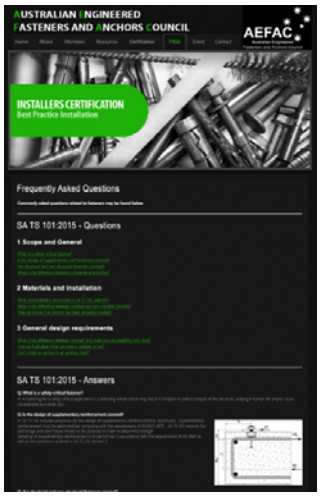
SA TS 101—2015: FAQ



- Refer to AEFAC's website www.aefac.org.au for FREQUENTLY ASKED QUESTIONS on SA TS 101

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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

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AEFAC INSTALLER CERTIFICATION PROGRAM

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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

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INSTALLER CERTIFICATION PROGRAM

Element		Europe†	U.S.‡
Training	- theoretical	•	•
Training	- practical	•	•
	- vertical-down		•
	- overhead		•
Exam	- theoretical	•	•
	- practical	•	•
	- independent assessment	•	•
	- re-certification (written and practical)	2 – 3 years	5 years

† 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)

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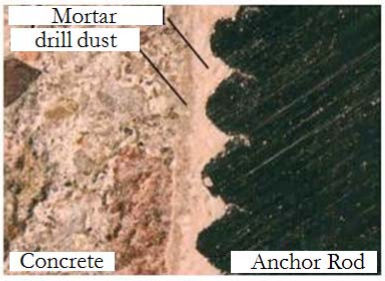
AEFAC INSTALLER CERTIFICATION PROGRAM

Importance of hole cleanliness

Drill dust will prevent proper bonding -> Strength reduction!

Well-cleaned



Poorly cleaned

Courtesy of IWB, University of Stuttgart

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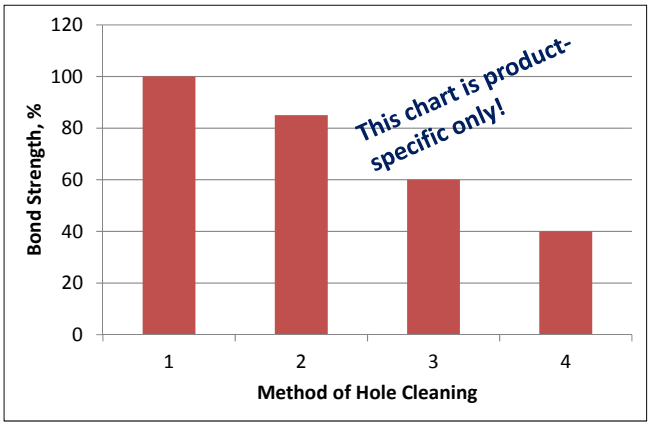
AEFAC Installer Certification Program

Sensitivity to cleaning method

Drill dust will prevent proper bonding -> Strength reduction!



Method of hole cleaning

1 – 2xblowing, 2xbrushing, 2xblowing

2 – 1xblowing, 1xbrushing 1xblowing

3 – 2xblowing

4 – No cleaning (drilling machine retracted 3 times)

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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

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AEFAC Installer Certification Program

- **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

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AEFAC Installer Certification Program

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AEFAC Installer Certification Program

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Installer Certification Program – Overhead Injection

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INSTALLER CERTIFICATION PROGRAM – OVERHEAD INJECTION

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But I've been doing it *this way* for *years!*

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AEFAC Technical Note – Engineering General Notes

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AEFAC

TECHNICAL NOTE: GUIDELINE FOR THE SPECIFICATION OF FASTENINGS TO CONCRETE – ENGINEERING GENERAL NOTES

VERSION 1.0

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 4).
2. Installation of the fastener(s) 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 6).

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 cleaning, 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

Fastenings for use in concrete in safety-critical applications should have a prequalification that is compatible with the design provisions stipulated in SA TS 101:2015 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.

A recommendation for the minimum information to be be included in the specification for different types of fasteners is included in the Appendix 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.

AEFAC Technical Note: Engineering General notes for SA TS101-2015, 22/09/2016

Page 1 of 8

[HTTP://WWW.AEFAC.ORG.AU/DOCUMENTS/AEFAC-TN-ENG-GEN-NOTES.PDF](http://www.aefac.org.au/documents/AEFAC-TN-Eng-Gen-Notes.pdf)

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AEFAC Technical Note – Engineering General Notes

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.

Chemical	Manufacturer's name	
	Product name	
Anchor rod	Type	(E.g. Threaded rod)
	Diameter	(E.g. M12)
	Length (mm)	(E.g. 200mm)
	Finish/Coating	(E.g. Galvanised)
	Strength Grade	(E.g. Class 8.8)
	Depth of embedment (mm)	(E.g. 110mm)
Drill hole	Diameter (mm)	(E.g. 14mm)
	Depth (mm)	(E.g. 110mm)
	Drill type	(E.g. Carbide-tipped)
Max tightening torque (Nm)	If applicable	(E.g. 100 Nm)

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 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.*

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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.*

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CASE STUDY

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CASE STUDY

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

Source: www.wsbtv.com

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CASE STUDY

- 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**

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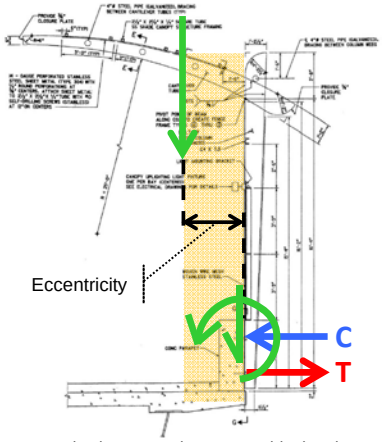
CASE STUDY

Bent anchor rod, some that is smooth – without thread

Epoxy removed from hole **seven years after installation**.



Typical column-cantilever assembly detail.

Source: 17th Street Bridge Canopy Failure Investigation, Report No. 2011.3732.0, WJE Associates Inc.

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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

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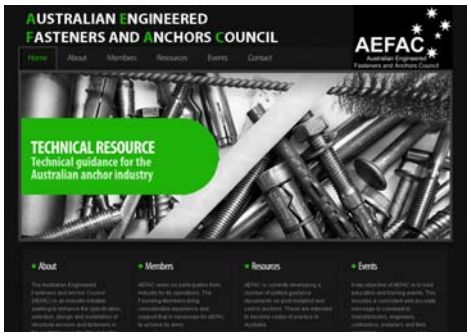
SUMMARY & ACKNOWLEDGEMENTS

Website

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



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SUMMARY & ACKNOWLEDGEMENTS

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Ancon Building Products

Hilti

Hobson Engineering

Stanley Black & Decker

Powers

ramsetreid innovative construction solutions

Würth

Supporting Members

Simpson Strong-Tie

All Thread Industries

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