Australian Engineered Fasteners & Anchor Council

Setting standards for the specification, selection & application of anchors & fasteners in Australia

15/08/2012

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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15/08/2012
Presentation Outline

1. Overview of AEFAC
2. Introduction to Post-Installed Anchors
3. Common Applications
4. Mechanics of Post-Installed Anchors
5. Factors influencing Performance
6. Failure Modes
7. Suitability Qualification
8. Selection
9. Design
10. Installation – General
11. Examples of Failures
Overview of AEFAC – Industry review

AS3600
Cl. 14.3 (d) Fixings

“In the case of shallow anchorages, cone-type failure in the concrete surrounding the fixing shall be investigated taking into account edge distance, spacing, the effect of reinforcement, if any, and concrete strength at time of loading.”

By contrast:

EOTA TR029
Cl. 1.4 Safety

“Anchorages carried out in accordance with these design methods are considered to belong to anchorages, the failure of which would cause risk to human life and/or considerable economic consequences.”

Overview of AEFAC – Looking abroad

Europe

- ETAG 001 – Guideline for European Technical Approval of Metal Anchors for use in Concrete

United States of America

- ACI 318 – Appendix D Anchoring to Concrete (design)
- ACI 355.2 – Qualification of post-installed mechanical anchors in concrete and commentary (qualification)
- ACI 355.4 – Qualification of post-installed adhesive anchors in concrete and commentary (qualification)
Overview of AEFAC – Industry review

✓ Directional advancement of our largely unmonitored industry
✓ United approach
✓ Improved safety
✓ Minimum standards
✓ Consistency in test methods and specification
✓ Education

UNIQUE AND EXCITING DEVELOPMENT

Overview of AEFAC – Aims

1. Develop technical materials for the specification, selection and application of anchors and fasteners.
2. Appropriate training and education for design engineers and specifiers.
3. Improve installation practices via training and accreditation.
4. Safeguard the quality of anchors and fasteners through standardisation of specification and certification of products.
5. Conduct research and development to advance the industry.
Overview of AEFAC – Planned Outputs

Guideline for minimum performance specifications for anchors
For Manufacturers

Certified training for installation of anchors
For Contractors

Guideline for specification of anchors
For Designers

Guideline for field testing and certification of anchors
For Field Engineers

Overview of AEFAC – Formation

- Professor Emad Gad
  Swinburne University of Technology

- James Murray-Parkes
  Swinburne University of Technology

12 month journey:
- Concept development
- Lobbying
- Engagement

Formed to stop anchor failures!
Overview of AEFAC - Organization

Board of Founding Members
Chair: Professor Emad Gad
Ancon, Hilti, Hobson, ITW Construction Systems, Powers, Würth & Swinburne University of Technology

Director
David Heath

Technical Committee
Chair: Gary Connah
Members: James Murray-Parkes (Hobson), Johannes Krohse (Wurth), Neil Hollingshead (ITW), Ramil Crisolo (Hilti), Tarun Joshi (Powers)

General Members (near future)
Other industry participants
Overview of AEFAC - Scope

**Initial**
- Bonded anchors
- Cast-in anchors (headed studs, cast-in channel)
- Mechanical anchors

**Future**
- Screws
- Fasteners

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Family of Anchors

Cast-in-place
- Channel
- Headed Studs
- Threaded Sleeves/Ferrules
- L, J bolts
- Bent reinforcing bars

Post-installed
- Drill and Fix Anchors
- Bonded

Drill and Fix Anchors
- Direct Installations
- Capsule
- Injection

Mechanical
- Capsule
- Injection

Expansion Anchors
- Torque Controlled
- Under-cut Anchors

Displacement Controlled

• Unsaturated polyester
  • Vinyl ester
  • Epoxy

• Unsaturated polyester
  • Vinyl ester
  • Epoxy
  • Cementitious

Pros
- High loading capabilities with mechanical Interlock
- Less sensitive to installation errors
- Can be installed in heavily reinforced elements
- The structure can be pre-designed by appropriate reinforcement to withstand external loads

Cons
- Layout and planning problems
- Not flexible for fastened part adjustments (change in design)
Post-installed anchors

**Pros**
- High loading capabilities *(can be designed as if cast-in depending on the type of anchor)*
- Flexible for layout adjustments
- Wide range of sizes and types available
- Some may be removed after use in temporary applications
- Immediate loading is possible (mechanical)

**Cons**
- Less understood
- Difficulties in densely reinforced concrete
- Need skilled trained staff for proper installations
- Proper storage conditions for adhesive systems

Post-installed anchors

**Torque-controlled expansion anchors**
- Through-bolt
- Thick-walled sleeve
- Thin-walled sleeve
- Shield-type

**Deformation-controlled**
- “Drop-in”

**Undercut**
- Undercut
- Self-undercut
- Screw

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

(Source: Draft BS 8539)
Post-installed anchors - chemical

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Post-installed anchor applications

- Steel to Concrete Connections

- Concrete to Concrete Connections
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Mechanics

Keying
The tensile load, N, is in equilibrium with the supporting forces, R, acting on the base material.

Friction
The tensile load, N, is transferred to the base material by friction, R. To build up the friction an expansion force is necessary.

Bonding
An adhesive bond is produced between the anchor rod / rebar and the mortar and between mortar and drill hole walls.
Mechanics – chemical anchors

- Combination of “glueing” and keying

![Diagram of concrete, mortar, anchor rod, and forces](image)

Cohesive forces ↔ Adhesive forces

Concrete

Mortar

Anchor rod

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Strength of substrate

- Hollow base materials
- Solid Bricks
- Concrete / Natural Stone

Performance considerations – hole preparation

- Hammer drilled hole
- Diamond cored hole
- Wet and dry holes
- Well cleaned hole

The chemical anchor should be suitable to conditions of the hole and the type of drilling method.
Anchor spacing and edge distance

Performance considerations – type of load
Performance considerations - mechanical

- Proper installation eg tightening torque
- Acceptable “load to deformation” behaviour
- Perform on a long term basis - functionality
- Smaller edge and spacing requirements might cause problems with some mechanical anchors
- Variety of versions for different applications
- Capable of very high loadings

Performance considerations – generic chemical

- Very sensitive to installation procedure – requires thorough hole cleaning
- Require careful handling and storage
- Must have an acceptable “load to deformation” behaviour.
- Must perform on a long term basis.
- Smaller edge and spacing requirements are possible – especially as there is no pre-stress due to installation.
- Variety of versions for different applications.
- Capable of very high loadings.
- Capable of resisting dynamic loads
- Must be non-toxic
Annular space and distribution of chemical

Service temperature

But... Performance is product-dependent!
### Types based on chemical composition

<table>
<thead>
<tr>
<th>Unsaturated Polyester</th>
<th>Vinylerster, Epoxy Acrylate, Methacrylate</th>
<th>Epoxy</th>
</tr>
</thead>
</table>

#### Advantages
- Low cost
- Rapid curing times in low temperature environments
- Less sensitive to mix ratios
- Good performance in hollow blocks and masonry

#### Disadvantages
- Not recommended for high risk applications
- More sensitive to hole preparation
- Unsuitable for diamond cored holes and large annular gaps due to shrinkage
- Limited chemical resistance

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### Types based on chemical composition

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#### Advantages
- Rapid curing times in low temperature environments
- Greater strength and chemical resistance relative to polyesters
- Good performance in damp concrete

#### Disadvantages
- More expensive than unsaturated polyester
- Less sensitivity to hole preparation
- Limited suitability to diamond cored holes
Types based on chemical composition

Unsaturated Polyester  Vinylester, Epoxy Acrylate, Methacrylate  Epoxy

Advantages

✓ Greater strength and chemical resistance relative to polyesters and vinylesters
✓ Good performance in damp concrete
✓ Better chemical resistance

Disadvantages

❖ More expensive than polyester and vinylester
❖ Relatively, longer period of curing
❖ More sensitive to temperature effects

Epoxy vs Polyester

![Graph comparing Epoxy and Polyester](image)
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Failure modes

Anchorage performance is always an assembly performance.

- Fastened element
- Base material
- Chemical anchor
Failure modes

Failure modes - Tension

Steel Failure

Concrete Cone

Pullout Failure

Concrete Splitting
Failure modes - Tension

- Steel Failure
- Concrete Edge
- Steel Bending
- Concrete Pryout

Failure modes - Shear

- Steel Failure
- Concrete Edge
- Steel Bending
- Concrete Pryout
Failure modes – Shear (without lever arm)

Failure modes – Shear (with lever arm)
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Areas of qualification

- Which product will I use?
- How will I know that it is really “fit for purpose”?

1. Manufacturing of the products
2. Compliance to design codes/standards
3. Performance of the products
Who may be involved if an anchor fails?

- Manufacturer
- Contractor
- Designer/Engineer/Specifier
- Project Manager
- Project/Property Owner
- Responsible Government Entity

- Complying manufacturing processes
- Properly designed and specified anchors
- Properly installed and inspected anchors

Widely used anchor design standards

- ACI 318-11
- ETAG 001

[Images of ACI 318-11 and ETAG 001 standards]
Concrete Capacity Design model

- Highly accurate
- Calculation of load bearing capacities at different load cases and different anchor configurations.
- Highly descriptive of the critical failure modes.
- Requires independently tested test reports to be used as an integral part of the design, installation and qualification process involved in using the anchor.

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Anchor Selection

The selection of anchor will depend on the requirements of the application.

- What is the base material? Solid or hollow?
- What is the drilling method? Anchor orientation?
- Curing time required?
- What is the load bearing strength required?
- What is the required service temperature?

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Anchor Design

Steel Capacity
(Use $c_{cr,N}$ and $s_{cr,N}$)

Concrete Capacity
(Use $c_{cr,Np}$ and $s_{cr,Np}$)

Pull-Out Capacity
(Use $c_{cr,Np}$ and $s_{cr,Np}$)

Splitting Capacity
(Use $c_{cr,sp}$ and $s_{cr,sp}$)

Concrete Capacity
(Use $c_{cr,N}$ and $s_{cr,N}$)

Pull-Out Capacity
(Use $c_{cr,Np}$ and $s_{cr,Np}$)

Splitting Capacity
(Use $c_{cr,sp}$ and $s_{cr,sp}$)

Anchor Design – tension example (bonded anchor)

$N_{Rk,s} = A_s f_{sh}$

$N_{Rk,c} = N_{Rk,c}^0 \frac{A_{c,N}}{A_{c,N}} \Psi_{s,N} \Psi_{e,N}$

$N_{Rk,p} = N_{Rk,p}^0 \frac{A_{p,N}}{A_{p,N}} \Psi_{s,Np} \Psi_{e,Np}$

$N_{Rk,sp} = N_{Rk,sp}^0 \frac{A_{c,N}}{A_{c,N}} \Psi_{s,N} \Psi_{e,N} \Psi_{h,sp}$

$N_{Rk,sp} = N_{Rk,sp}^0 \frac{A_{c,N}}{A_{c,N}} \Psi_{s,N} \Psi_{e,N} \Psi_{h,sp}$

$N_{Rk,sp} = \pi d h_e \tau_{sh}$

$k_f = 7.2$ (for cracked concrete)

$k_i = 10.1$ (for non-cracked concrete)

$S_{cr,N} = 3 h_d$

$S_{cr,Np} = 20 d \left( \frac{f_{Rk,c}}{7.5} \right)^{0.5} \leq 3 h_d$
**Anchor Design – combined loads**

\[ \beta_N = \frac{N_{sd}}{N_{Rd}} \]

\[ \beta_V = \frac{V_{sd}}{V_{Rd}} \]

- \( N_{sd} = \) Design value of ACTING Tension load
- \( N_{Rd} = \) Design Value of tension RESISTANCE
- \( V_{sd} = \) Design value of ACTING shear load
- \( V_{Rd} = \) Design Value of shear RESISTANCE

**Anchor Design – Guidelines**

**European**
Qualification: ETAG 001, Part 1 – 5
Design: ETAG 001 Annex C
http://www.eota.be/pages/home/

**American**
Qualification: ACI 355.2 (mechanical) & 355.4 (chemical)
Design: ACI 318 – Appendix D
http://www.concrete.org/general/home.asp

Software exists to design "qualified" anchors. Ask your manufacturer!
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Proper Installation is key to performance
Installation – Mechanical Anchors

Drill  Clean  Insert  Torque

Installation – Chemical Anchors

Waste product until even consistency achieved

Drill  Clean  Inject  Insert  Cure
Tools for Installation

- ALL
  - Cleaning brush
  - Blow-out pump

- CAPSULE
  - Threaded rod setting tool
  - Socket

- CARTRIDGE
  - Chemical Dispenser
  - Chemical Tube
  - Mixing Nozzle

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Anchor failures do happen!

Summary

- AEFAC is an industry initiative lifting quality and safety standards for the Australian post-installed anchor industry.
- Post-installed anchors offer many benefits such as high load capacity and a flexible layout in diverse substrates.
- Qualification standards exist for quality assurance.
- Comprehensive design guidelines exist, software exists for simplified specification.
- Performance is sensitive to installation procedure.
- Always follow manufacturer’s installation instructions.
- If in doubt ask manufacturer’s technical support.
THANK YOU!