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 David Heath: djheath@swin.edu.au
1. Overview of AEFAC
2. Examples of anchors
3. Types of anchors
4. Mechanics of post-installed anchors
5. Installation
6. Factors affecting performance
7. Transfer of load to anchors
8. Modes of anchor failure
9. ETAG Design Method
10. Failure examples
11. Questions and answers
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.”

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

UNIQUE AND EXCITING DEVELOPMENT
AEFAC

Overview of AEFAC – Industry needs

To:
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

Guideline for minimum performance specifications for anchors (by manufacturers)
Certified training for installation of anchors (for contractors)
Guideline for specification of anchors (for use by engineers)
Guideline for field testing and certification of anchors (for field engineers)
Overview of AEFAC – The concept

Founders
• Professor Emad Gad
  Swinburne University of Technology
• James Murray-Parkes
  Swinburne University of Technology

12 month journey:
- Concept development
- Lobbying
- Engagement

Stimulated by anchor failure in Melbourne

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

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
Engineering representation from Founding Members, industry participants invited to be Technical Members, plus technical advisors

General Members
Other industry participants

Overview of AEFAC - Aims

<table>
<thead>
<tr>
<th>Term</th>
<th>Goals</th>
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<tbody>
<tr>
<td>Short Term</td>
<td>• Minimum performance specifications for manufacturers</td>
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<td>• Guideline for specification of anchors by engineers</td>
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<td></td>
<td>• Commence lobby of ABCB, Worksafe, Standards Australia</td>
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<td>• Provide educational seminars</td>
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<tr>
<td>Medium Term</td>
<td>• Guideline for field testing and certification of anchors</td>
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<td></td>
<td>• Develop certification program for training of installers</td>
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<tr>
<td></td>
<td>• Continue lobby with ABCB, Standards Australia, Worksafe</td>
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<tr>
<td></td>
<td>• Further develop educational materials</td>
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<tr>
<td>Long Term</td>
<td>• Maintain developed Guidelines/Standards</td>
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<td></td>
<td>• Develop new guidelines for other fasteners</td>
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<tr>
<td></td>
<td>• Continue the educational development and delivery</td>
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<td></td>
<td>• Develop and maintain a certification database</td>
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Overview of AEFAC - Scope

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

Future
- Screws
- Fasteners

EXAMPLES OF ANCHORS
**Examples**

- Types of Anchors
- Working Principles
- Different types of Adhesives
- Installation procedure

- Tension failure modes
- Shear failure modes
- ETAG design method for adhesives
Cast-in-place anchors

Pros
- High loading capabilities
- Mechanical Interlock
- 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)
- Tedious installation and potential for errors
Cast-in-place anchors

Cast-in-place channels
Cast-in-place channels

Curtain wall glass element

Curtain wall bracket (system Gartner)

HTA channel

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Mechanical Anchors

Undercut Anchors

Expansion Anchors

Screw Anchors

Reverse Undercut

Forward Undercut

Displacement Controlled

Torque Controlled

Post-Installed (Mechanical Anchors)

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Post-Installed (Mechanical Anchors)

**Installation Procedure**

1. **Undercut Anchors**
   - Reverse Undercut
   - Forward Undercut

2. **Expansion Anchors**
   - Displacement Controlled

3. **Screw Anchors**
   - Torque Controlled

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Mechanical anchor installation

Post-Installed (Adhesive Anchors)

Adhesive Anchors

Capsule Systems
- Unsaturated polyester, Epoxyacrylate, Vinylester, Epoxy

Injection System
- Unsaturated polyester
- Epoxyacrylate, Vinylester
- Epoxy, Cementitious
Unsaturated Polyesters

- Polymer type with styrene monomer
- Styrene based (concerns over its safety both transport and health)
- Styrene-free are now available (improved performance over the styrene based)
- Gives a reasonable strength performance for the majority of applications and is best suited to fixings into hollow blocks or masonry.
- Low cost due to lesser amount of catalyst
- Limited chemical resistance
- Fast cure
- Less sensitive to mix ratios (10:1 ratio) as chemical reaction starts as long as the base resin in contact with ANY amount of the catalyst.

Epoxy acrylate / Vinylester

- These resins should not be confused with pure Epoxy
- Cure in the same way as polyesters (fast cure and good low temperature performance)
- Fast cure
- Higher performance than polyesters due to different polymer
- Better chemical resistance
- Possess improved thermal, physical and chemical properties
- Available in styrene based or styrene-free formulations
- Less sensitive to mix ratios (available in 10:1 to 3:1 ratios) as chemical reaction starts as long as the base resin in contact with ANY amount of the catalyst.
**EPOXY**

- Cure slower than Polyester/Epoxyacrylate/Vinylester as it is non-catalytic resin, cure by addition cure mechanism
- Complete mixing of pure epoxies is vital
- Supplied at closer to equal mix proportions (1:1 to 3:1)
- Slow curing (advantageous in hot climates and also for rebars)
- Virtually no shrinkage
- Considerable better load performance
- Suitable in diamond cored holes and for large annular gaps
- Good chemical resistance and excellent adhesion
- Generally not recommended for use below +5degC
- Suitable for underwater applications due to its water impervious nature.
- Good thermal and mechanical properties and excellent chemical resistance
- Good bonding properties

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**Post-installed anchors - chemical**

**Resin matrix**
- Benefits of organic
  - high fluidity
  - fast curing
  - strong bond
- Benefits of inorganic
  - insensitive to humidity
  - post hardening
  - heat resistance

**Fillers**
- quartz sand
- quartz powder
- glass spheres
- ...

**Hybrid Systems**
INSTALLATION - Proper hole cleaning technique

Chemical anchor installation

![Chemical anchor installation images](image1)

INSTALLATION – Hollow base material

Chemical anchor installation

![Chemical anchor installation images](image2)
MECHANICS OF POST-INSTALLED ANCHORS

Working principles of post-installed anchors

**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 borehole walls.
Performance considerations in the use and design of mechanical anchors:

- Must be properly installed
- Must have an acceptable “load to deformation” behaviour
- Must perform on a long term basis
- Smaller edge and spacing requirements.
- Variety of versions for different applications.
- Capable of very high loadings.

Performance considerations in the use and design of bonded anchors:

- Very sensitive to installation procedure – requires thorough hole cleaning. Must be properly installed.
- 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
- It must have a very low shrinkage
- It must be non-toxic
**Post-installed anchors**

**Pros**
- High loading capabilities *(can be designed as if cast-in depending on the type of anchor)*
- With design criteria
- Flexible for layout adjustments
- Relatively, faster and easy installation
- Wide range of sizes and types available to fulfil the requirements
- Some may be completely 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

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**Post-installed anchors – Adhesive anchor elements**

- Anchor rods
- Rebars
- Internally threaded rods
- Special elements
- Plastic sieve
- Injection Systems
- Capsule Systems
FACTORS AFFECTING PERFORMANCE

Factors affecting performance

- Load on the Anchor & Load Transfer Mechanism
- Base Material Strength & Dimension
- Anchor Spacing & Edge Distance
- Depth of Embedment
- Tightening Torque
- Reinforcement in Base Material
- Temperature (Fire)
- Corrosion
- Type of Adhesive (BOND STRENGTH)
- Method of drilling holes (Diamond Cores or Hammer Drills)
- Chemical resistance
- Construction Sequence
The presence of reinforcement can significantly improve the resistance to breakout.

Other factors

- Creep
- Fatigue
- Fire
- Durability
- Non-Cracked Concrete (Compression zone)
- Cracked Concrete (Tension zone)
- Special applications
EOTA Technical Report TR - 029
Design of Bonded Anchors

- EOTA - European Organisation for Technical Approvals
- ETA - EUROPEAN TECHNICAL APPROVAL
- ETAG - EUROPEAN TECHNICAL APPROVAL GUIDELINE
MODES OF ANCHOR FAILURE

TENSION LOAD
TENSION LOADS - Possible failure modes for bonded anchors

<table>
<thead>
<tr>
<th>a) Concrete cone failure</th>
<th>Pull-out failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>b) Failure mortar/concrete</td>
<td>c) Failure threaded rod/mortar</td>
</tr>
<tr>
<td>e) Steel failure</td>
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</table>

Splitting Failure

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Anchor performance is highly dependent on the load bearing capacity of the volume of base material carrying the external anchor loads. The deeper the embedment, the greater is the volume of base material bearing the load (provided pull-out, splitting and steel capacities are higher).

Anchor performance is reduced as a result of truncated influence cone.
Influence cone overlaps reduces the tensile capacity of involved anchors.

Concrete breakout
TENSION LOADS - Anchor material failure

F_{external}

SHEAR LOAD
Anchor material (Steel) failure in shear: without lever arm

Anchor material behaviour in shear: with lever arm (bending)
Anchor material behaviour in shear: bending

![Figure 4.9](image)

Fixure without (a) and with (b) restraint

Anchor behaviour in shear: Concrete Failures

Concrete Pry-out failure

Concrete Edge failure

\[ A_{V} = (2 \cdot 1.5C_t) \cdot 1.5C_e = 4.5 \cdot C_t \cdot C_e \]
TRANSFER OF LOAD TO ANCHORS

Load direction
Load direction

Is this simultaneous distribution of load?

Load transfer

Which anchor is carrying which load?
Anchor design considerations

Anchor design considerations: 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
EOTA Technical Report TR-029
Design of Bonded Anchors

DESIGN STEPS

Anchor design considerations: Tension Loads

STEEL  CONCRETE CONE  Pull-Out / Bond  SPLITTING

Tension

Steel  Concrete

Concrete cone  Pull-out  Splitting

Find smallest design resistance
### EOTA Design Method for Bonded anchors – Tension Loads

#### Steel Capacity

\[ N_{Rk,s} = A_s f_{sk} \]

#### Concrete Capacity

(Use \( c_{cr,N} \) and \( s_{cr,N} \))

\[ N_{Rk,c} = N_{Rk,c}^0 \frac{A_{c,N}}{A_{c,N}^0} \Psi_{s,N} \Psi_{ec,N} \Psi_{re,N} \]

#### Pull-Out Capacity

(Use \( c_{cr,Np} \) and \( s_{cr,Np} \))

\[ N_{Rk,p} = N_{Rk,p}^0 \frac{A_{p,N}}{A_{p,N}^0} \Psi_{s,Np} \Psi_{ec,Np} \Psi_{re,Np} \Psi_{h,sp} \]

#### Splitting Capacity

(Use \( c_{cr,sp} \) and \( s_{cr,sp} \))

\[ N_{Rk,sp} = N_{Rk,sp}^0 \frac{A_{c,N}}{A_{c,N}^0} \Psi_{s,N} \Psi_{ec,N} \Psi_{re,N} \Psi_{h,sp} \]

- **Concrete Capacity**: \( k_c = 7.2 \) (for cracked concrete) \( k_c = 10.1 \) (for non-cracked concrete)

- **Pull-Out Capacity**: \( S_{cr,Np} = 3 h_{ef} \)
- **Splitting Capacity**: \( S_{cr,N} = 20 d \left( \frac{T_{Rk,s}}{7.5} \right)^{0.5} \leq 3 h_{ef} \)

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### EOTA Design Method for Bonded anchors – Tension Loads

**TENSION – Concrete Failure Influence/Actual Areas**

- **Concrete Failure**: \( A_{C,N} = (c_1 + s_1 + 0.5 s_{cr,N}) \cdot (c_2 + s_2 + 0.5 s_{cr,N}) \)
  - if: \( c_1 < c_2 \leq c_{cr,N} \)
  - if: \( S_1 < S_2 \leq S_{cr,N} \)

- **Anchor Group**: \( A_{N,N} = A_{N} \cdot A_{N} \)

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**EOTA Design Method for Bonded anchors – Tension Loads**

**TENSION – Pull-Out Failure Influence/Actual Areas**

![Diagram of anchor system with equations]

c) group of four anchors at a corner of concrete member

**EOTA Design Method for Bonded anchors - Tension Loads**

- **Edge influence**
  \[ \Psi_{s,N} = 0.7 + 0.3 \frac{c}{c_{cr,N}} \leq 1.0 \]

- **Dense Reinforcement**
  \[ \Psi_{t,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0 \]

**Eccentricity**

\[ \Psi_{e,N} = \frac{1}{1 + \frac{2e_N}{S_{cr,N}}} \leq 1.0 \]

**NOTE:** The influence factors for “edge distance” and “eccentricity” varies for different modes.

**Anchor Group**

\[ \Psi_{g,Np} = \Psi_{g,Np}^0 - \left( \frac{s}{s_{cr,Np}} \right)^{0.5} \Psi_{g,Np}^0 - 1 \geq 1.0 \]

\[ s = \text{mean value of all spacings} \]

\[ \Psi_{g,Np}^0 = \sqrt{n} - \left( \frac{d \tau_{Rk}}{k \sqrt{h_{ef} f_{ck,cahe}} \sqrt{h_{min}}} \right)^{1.5} \geq 1.0 \]

**Actual member depth**

\[ \Psi_{h,sp} = \left( \frac{h}{h_{min}} \right)^2 \leq 1 \]

\[ 1 \leq \Psi_{h,sp} \leq \left( \frac{2.3 h_{ef}}{h_{min}} \right)^2 \]

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EOTA Design Method for Bonded anchors—SHEAR Loads

- **Shear load without lever arm**

  \[ V_{Rk,s} = \frac{0.5A_{\text{st}}f_{uk}}{\gamma_{Ms}} \]

  \[ M_{Rk,s} = M_{Rk,s}^0 (1 - N_{sd} / N_{Rd,s}) \]

  \[ N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}} \]

- **Shear load with lever arm**

  \[ V_{Rk,s} = 0.5A_{\text{st}}f_{uk} \]

  \[ M_{Rk,s} = M_{Rk,s}^0 \]

  \[ N_{sd} = \text{Design Tension Load} \]

  \[ M_{Rk,s}^0 = 1.2W_{ef}f_{uk} \]

Stressed Area of anchor (\( A_{\text{st}} \))

Characteristics of shear load

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EOTA Design Method for Bonded anchors—Shear Loads

\[ V_{Rk,c} = V_{Rk,c}^{0} \left( \frac{A_{c,V}}{A_{c,V}} \right) \psi_{s,V} \psi_{e,V} \psi_{h,V} \psi_{a,V} \]

Where:
- \( V_{Rk,c} \): Shear force
- \( V_{Rk,c}^{0} \): Basic shear force
- \( A_{c,V} \): Concrete area
- \( A_{c,V} \): Concrete area
- \( \psi_{s,V} \): Eccentricity factor
- \( \psi_{e,V} \): Type of Reinforcement factor
- \( \psi_{h,V} \): Correction factor for member thickness "h"
- \( \psi_{a,V} \): Direction of loading factor

Influence of edges due to further edges

\[ V_{Rk,c}^{0} = k_1 \cdot d_{ef} \cdot h_{ef} \cdot \sqrt{f_{ck,cube}} \cdot c_{1}^{1.5} \]

Where:
- \( k_1 = 1.7 \) for cracked concrete
- \( k_1 = 2.4 \) for non-cracked concrete

NOTE: If the shear force on an anchor in a group is in opposite direction to other anchor in the group, the verification of pry-out failure for the most unfavourable anchor of the group should be considered by taking into account the influences of both, edge as well as spacing distances.
EOTA Design Method for Bonded anchors—Shear Loads

Edge influence due to further edges

\[ \Psi_{s,V} = 0.7 + 0.3 \frac{c_2}{1.5c_1} \leq 1.0 \]

Eccentricity

\[ \Psi_{e_c,V} = \frac{1}{1 + \frac{2c_{e_V}}{3c_1}} \leq 1.0 \]

Type of Reinforcement

- 1.0 (non-cracked concrete and cracked concrete without edge reinforcement)
- 1.2 (cracked concrete with straight edge reinforcement \( \geq 12 \text{mm} \))
- 1.4 (cracked concrete with edge reinforcement and closely spaced stirrups, \( a \leq 100 \text{mm} \))

Correction factor for \( A_{e,V} / A_{e,V}^0 \) for member thickness "h"

\[ \Psi_{h,V} = \left( \frac{1.5c_1}{h} \right)^{0.5} \geq 1.0 \]

Direction of loading \( \alpha \leq 90^\circ \)

\[ \Psi_{\alpha,V} = \frac{1}{\sqrt{(\cos \alpha_V)^2 + \left( \frac{\sin \alpha_V}{2.5} \right)^2}} \geq 1.0 \]

EOTA Design Method for Bonded anchors—Combined Loads

Find smallest design resistance

Load combination

Find smallest design resistance
AEFAC

EOTA Design Method for Bonded anchors – Combined Loads

\[
\begin{align*}
\beta_N &= \frac{N_{sd}}{N_{Rd}} \\
\beta_V &= \frac{V_{sd}}{V_{Rd}}
\end{align*}
\]

- \(N_{sd}\) = 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

FAILURE EXAMPLES
Anchor material failure in shear

Anchor sheared-off during an earthquake.

Base material failure in tension

Anchor Failure due to poor quality of concrete
Anchors were completely pulled out as the tank tumbled down during the earthquake.

Chemical anchors were completely pulled out during an earthquake.
Mechanical anchors were completely pulled out as the concrete failed.

Base material cracking as a result of a relatively small edge distance.
11. Questions and Answers