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Australian **E**ngineered **F**asteners & **A**nchor **C**ouncil

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

For further information contact David Heath: djheath@swin.edu.au

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Participants

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Overview

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

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Overview of AEFAC – Industry review

<u>AS3600</u>

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.”

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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

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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

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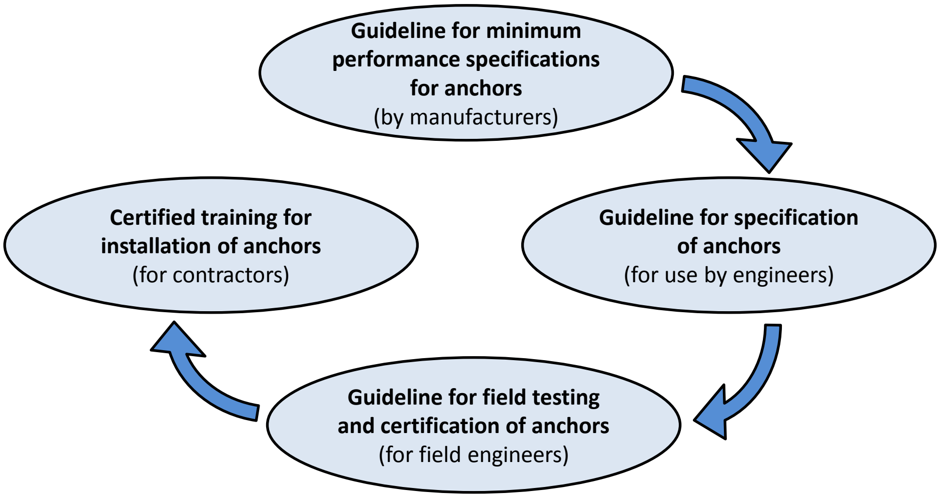
Overview of AEFAC – Industry needs



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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

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Overview of AEFAC – Looking abroad

Europe

- ETAG 001 – Guideline for European Technical Approval of Metal Anchors for use in Concrete
- CEN/TS 1992-4:2009 "Design of fastenings 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)

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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

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Overview of AEFAC - Aims

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

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Overview of AEFAC - Scope

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

Future
- Screws
- Fasteners

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EXAMPLES OF ANCHORS

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Examples

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Examples

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Examples

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Examples

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Examples

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Examples

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Examples

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

- Tension failure modes
- Shear failure modes
- ETAG design method for adhesives

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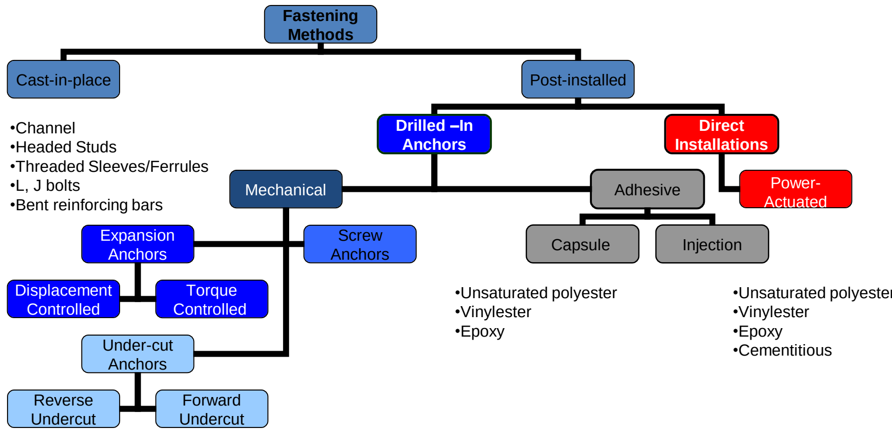

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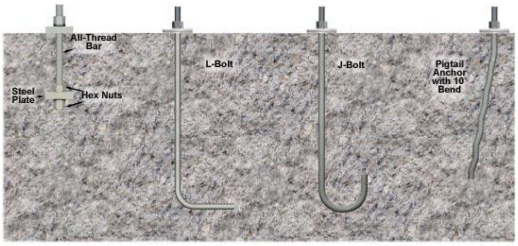
Cast-in-place anchors



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

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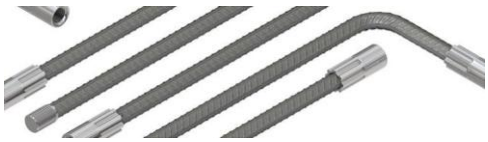
Cast-in-place anchors



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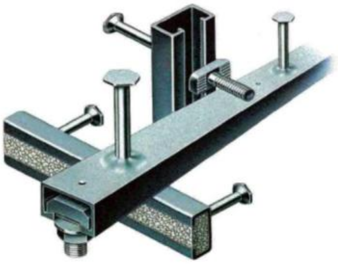
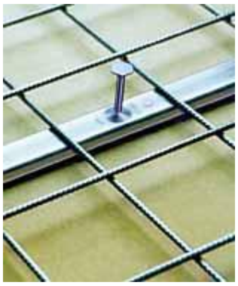
Cast-in-place channels





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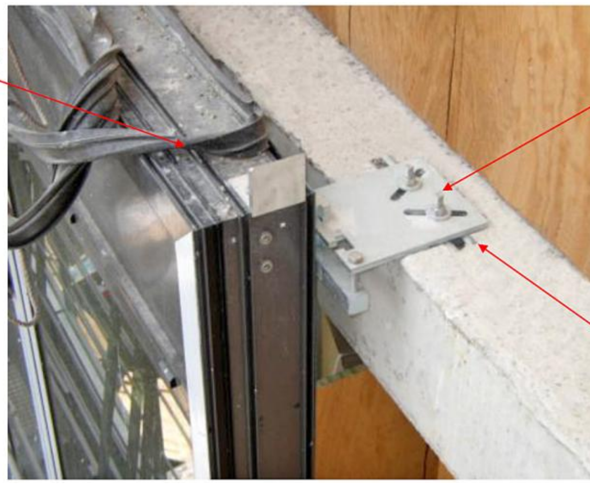
Cast-in-place channels



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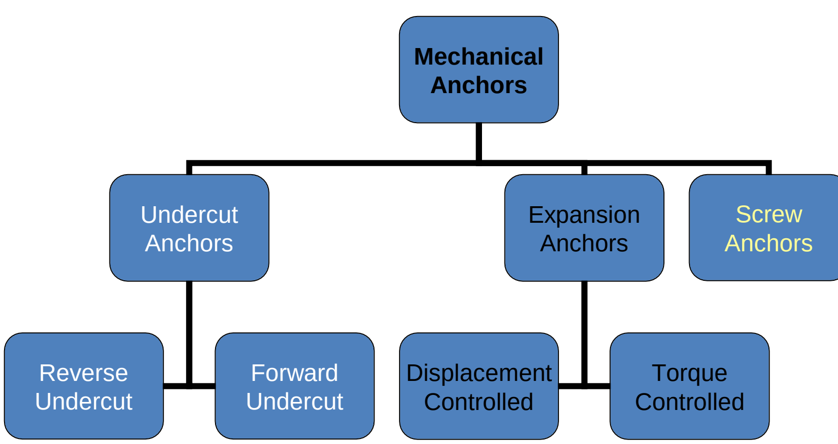
Post-Installed (Mechanical Anchors)



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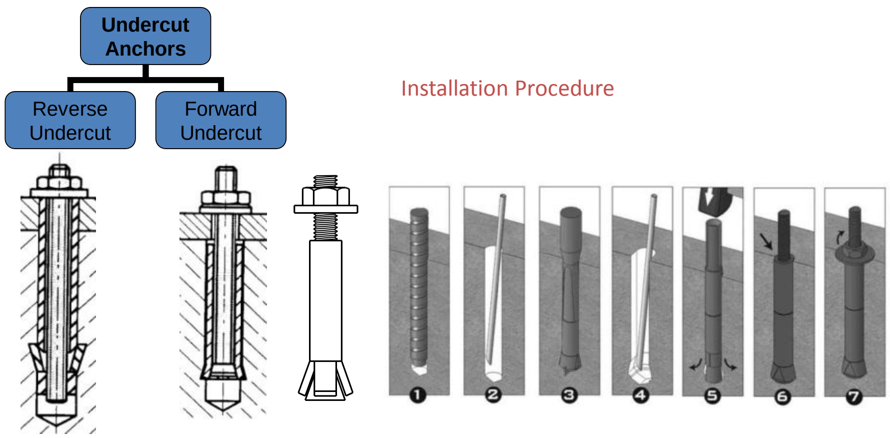
Post-Installed (Mechanical Anchors)



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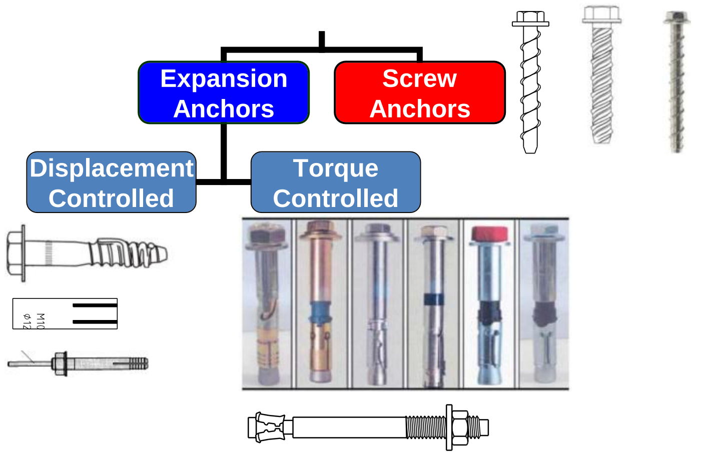
Post-Installed (Mechanical Anchors)



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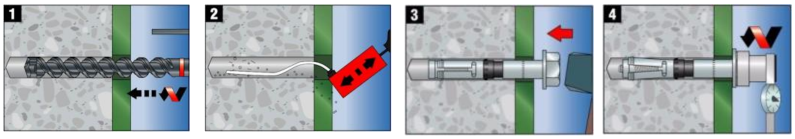
INSTALLATION - Proper hole cleaning technique

Mechanical anchor installation



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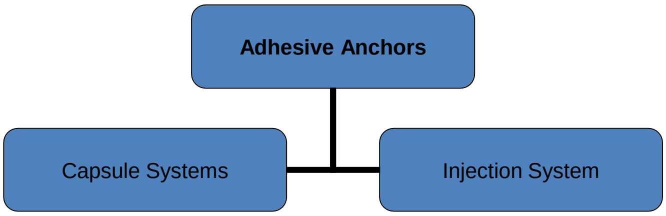
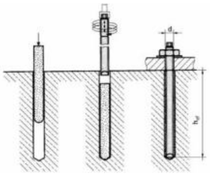
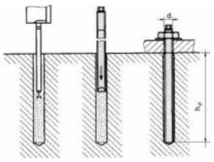
Post-Installed (Adhesive Anchors)



Unsaturated polyester,
Epoxyacrylate, Vinylester
Epoxy

Unsaturated polyester
Epoxyacrylate, Vinylester
Epoxy, Cementitious





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Post-Installed (Adhesive Anchors)

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.

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Post-Installed (Adhesive Anchors)

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.

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Post-Installed (Adhesive Anchors)

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

Hybrid Systems

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

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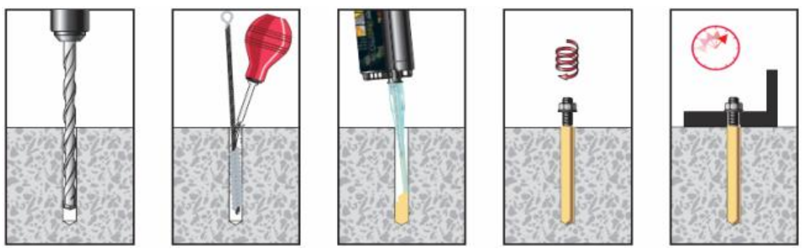
INSTALLATION - Proper hole cleaning technique

Chemical anchor installation



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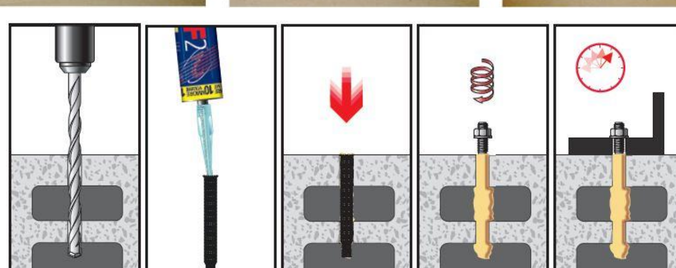
INSTALLATION – Hollow base material

Chemical anchor installation



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MECHANICS OF POST-INSTALLED ANCHORS

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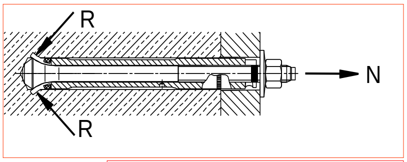
Working principles of post-installed anchors

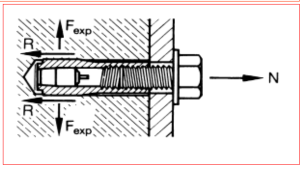
Keying

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



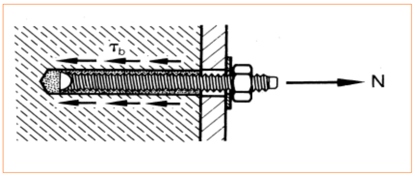
Friction

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



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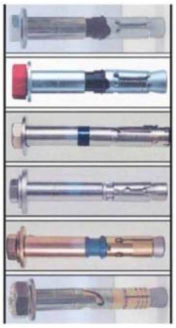
Post-installed anchors - Mechanical

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.

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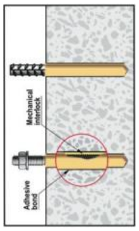
Post-installed anchors – Adhesive

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

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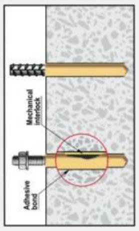
Post-installed anchors

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

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FACTORS AFFECTING PERFORMANCE

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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

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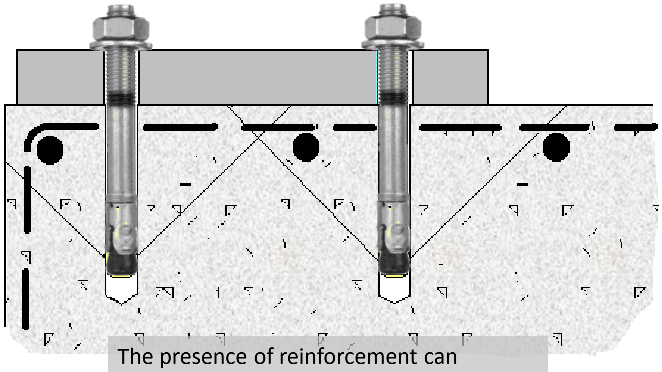
Effect of reinforcement



The presence of reinforcement can significantly improve the resistance to breakout.

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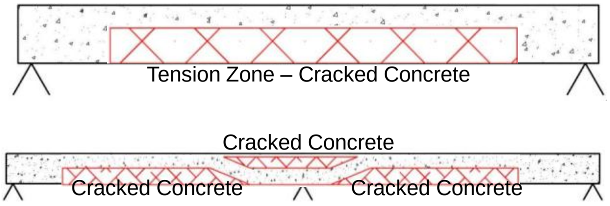
Other factors

- Creep
- Fatigue
- Fire
- Durability
- Non-Cracked Concrete (Compression zone)
- Cracked Concrete (Tension zone)
- Special applications



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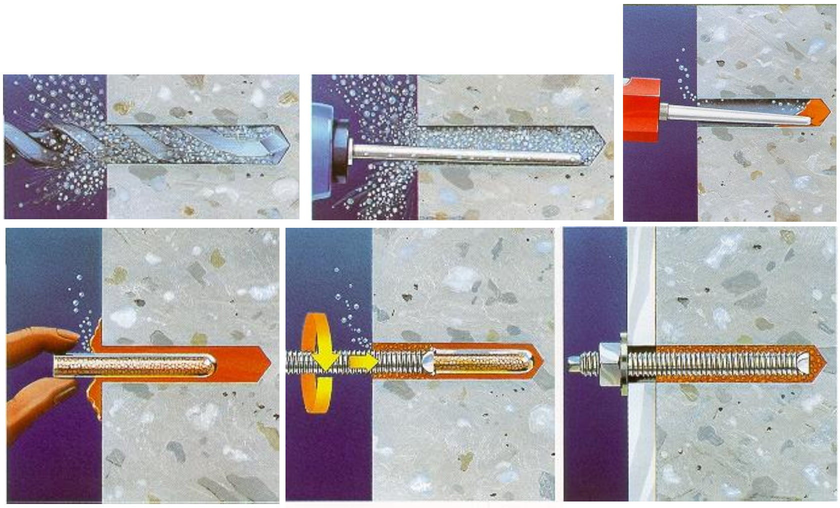
Special applications: underwater



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EOTA Technical Report TR - 029
Design of Bonded Anchors

- EOTA - European Organisation for Technical Approvals
- ETA - EUROPEAN TECHNICAL APPROVAL
- ETAG - EUROPEAN TECHNICAL APPROVAL GUIDELINE

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MODES OF ANCHOR FAILURE

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TENSION LOAD

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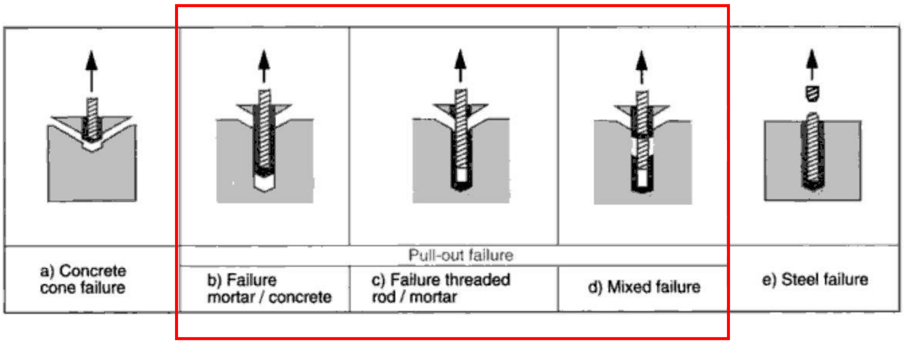
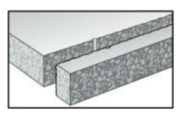
TENSION LOADS - Possible failure modes for bonded anchors



Splitting Failure



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TENSION LOADS - Possible failure modes for bonded anchors

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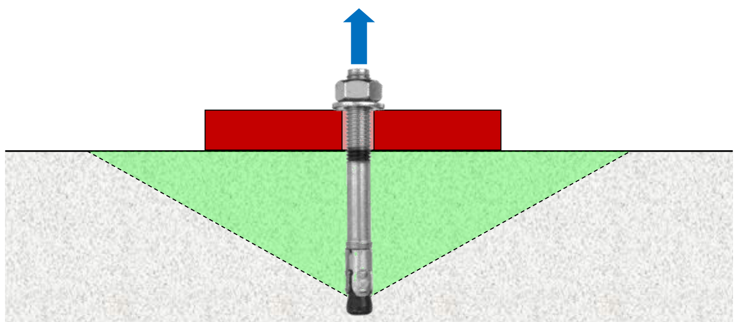
Depth of embedment



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).

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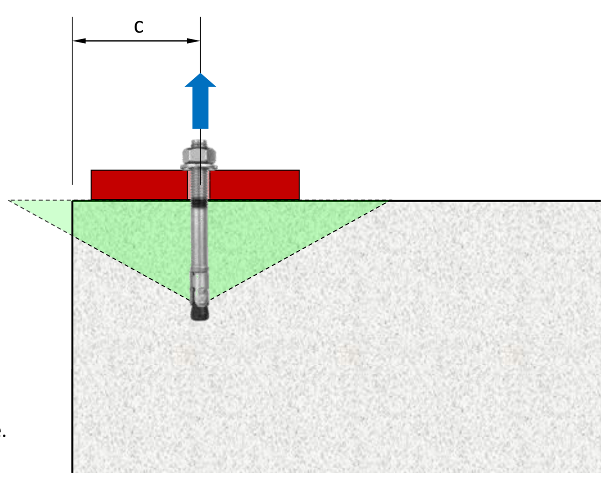
TENSION LOADS -Edge distance effect



Anchor performance is reduced as a result of truncated influence cone.

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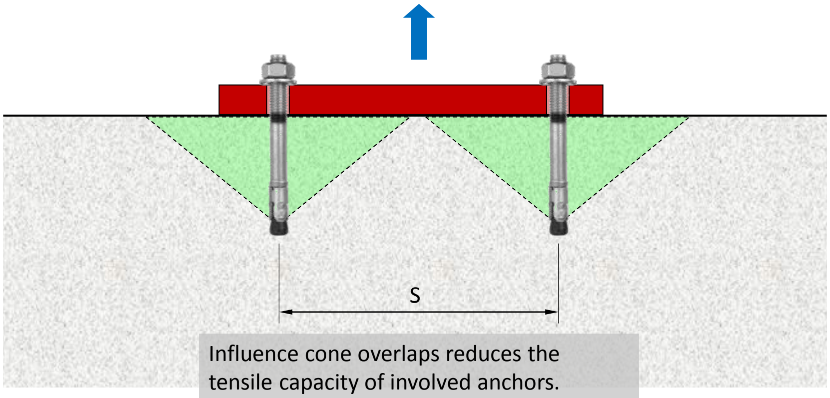
TENSION LOADS - Spacing distance effect



Influence cone overlaps reduces the tensile capacity of involved anchors.

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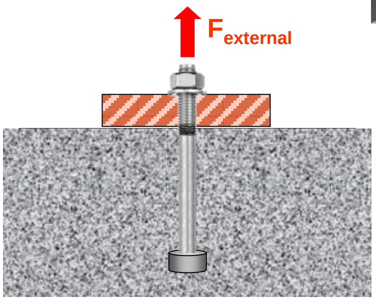
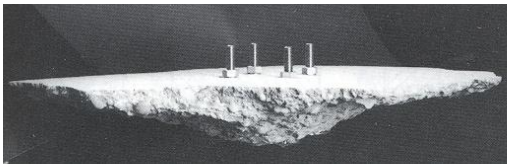
TENSION LOADS - Concrete breakout





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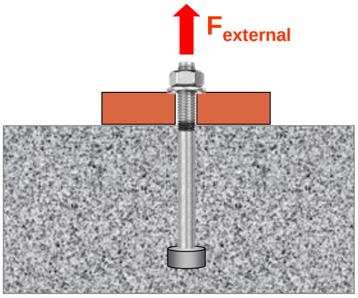
TENSION LOADS - Anchor material failure



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SHEAR LOAD

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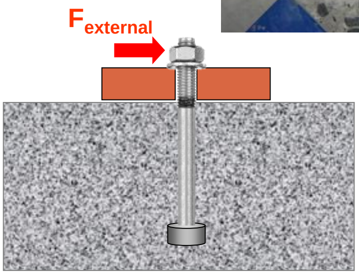
Anchor material (Steel) failure in shear: without lever arm



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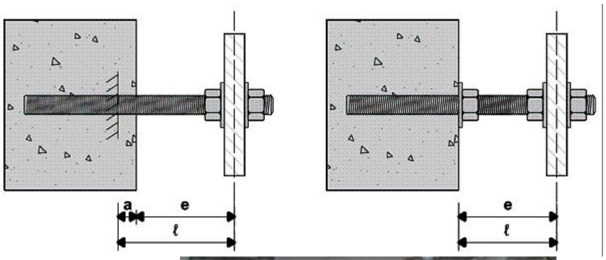
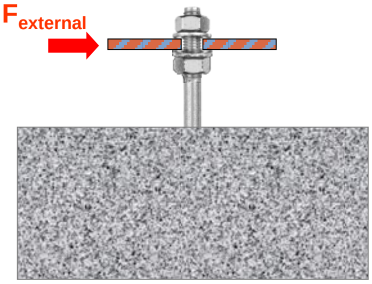
Anchor material behaviour in shear: with lever arm (bending)





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Anchor material behaviour in shear: bending

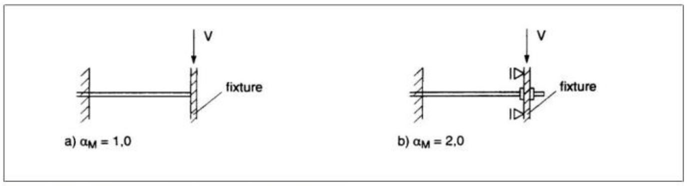

Figure 4.9 Fixture without (a) and with (b) restraint

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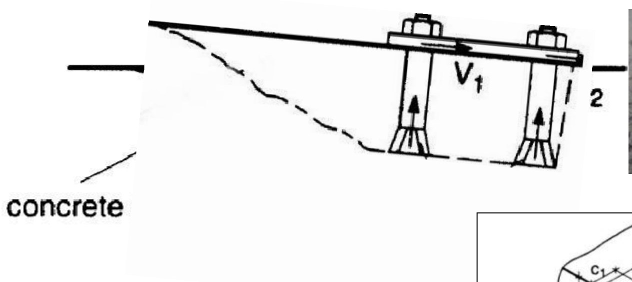
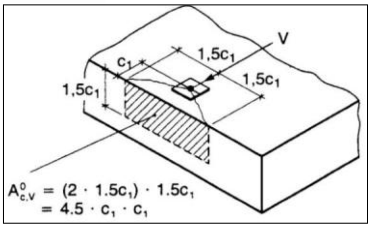
Anchor behaviour in shear: Concrete Failures

Concrete Pry-out failure



Concrete Edge failure



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TRANSFER OF LOAD TO ANCHORS

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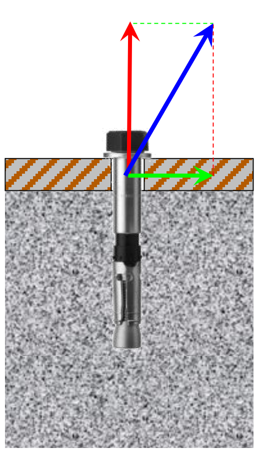
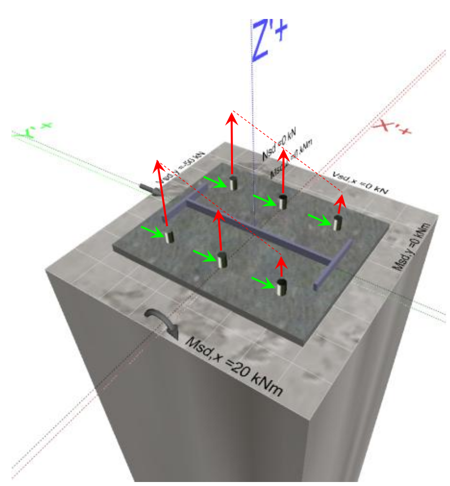
Load direction





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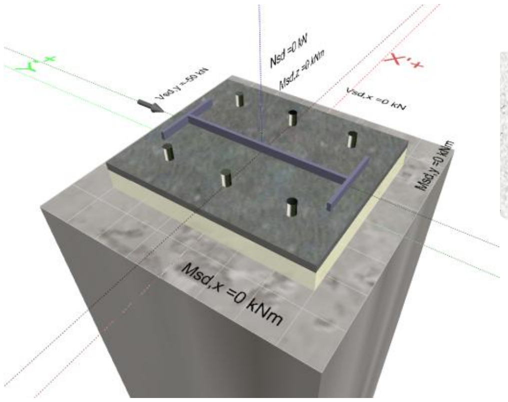
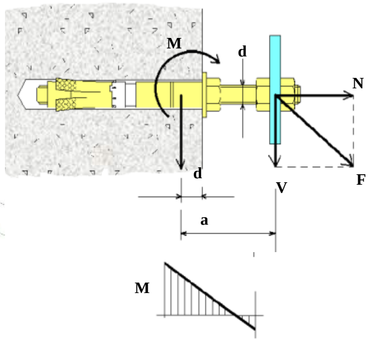
Load direction





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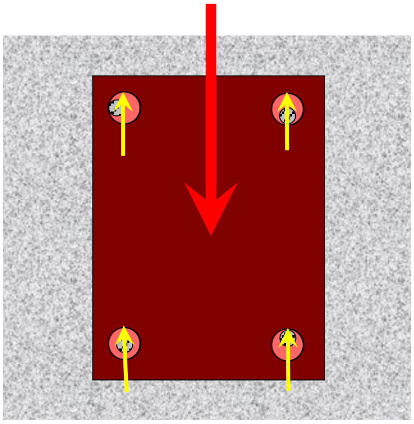
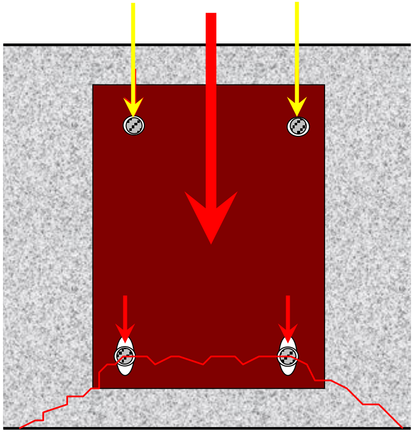
Load transfer



Is this simultaneous distribution of load?



Which anchor is carrying which load?

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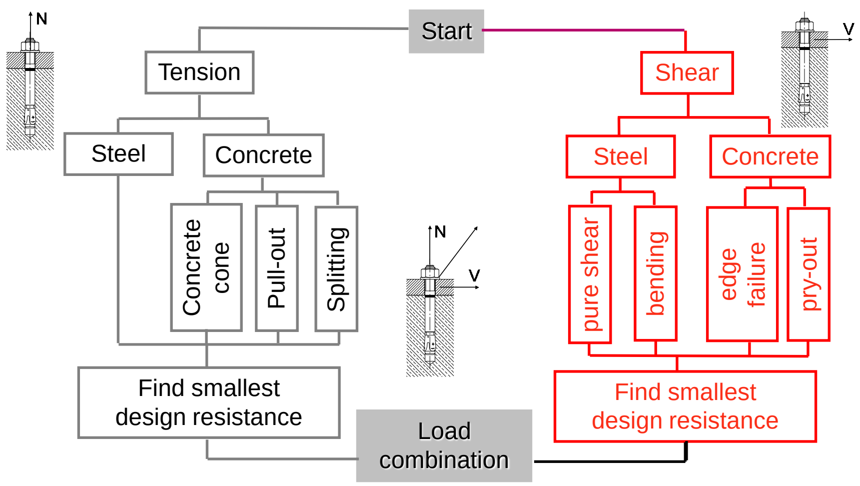
Anchor design considerations



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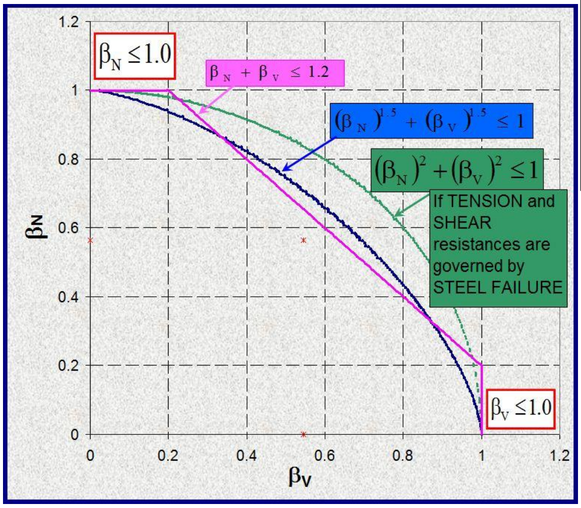
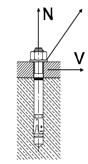
Anchor design considerations : Combined Loads



$$\beta_N = \frac{N_{Sd}}{N_{Rd}}$$

$$\beta_V = \frac{V_{Sd}}{V_{Rd}}$$



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

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EOTA Technical Report TR-029
Design of Bonded Anchors

DESIGN STEPS

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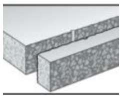
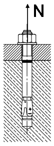
Anchor design considerations: Tension Loads

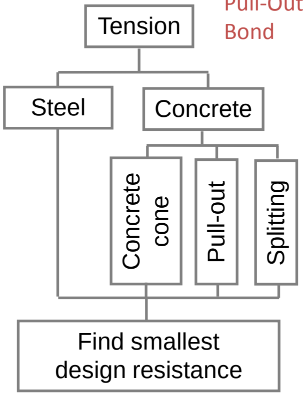

STEEL


CONCRETE CONE


Pull-Out / Bond


SPLITTING





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EOTA Design Method for Bonded anchors – Tension Loads

Steel Capacity

$$N_{Rk,s} = A_s . f_{uk}$$

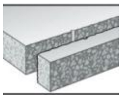
Concrete Capacity (Use $c_{cr,N}$ and $s_{cr,N}$)

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} . \Psi_{s,N} . \Psi_{ec,N} . \Psi_{re,N}$$

Anchor Group

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

$$N_{Rk,p} = N^0_{Rk,p} \cdot \frac{A_{p,N}}{A^0_{p,N}} . \Psi_{s,Np} . \Psi_{ec,Np} . \Psi_{re,Np} . \Psi_{g,Np}$$



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

$$N_{Rk,sp} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} . \Psi_{s,N} . \Psi_{ec,N} . \Psi_{re,N} . \Psi_{h,sp}$$

Actual membe depth

Edge influence

Eccentricity

Dense Reinforcement

$$N^0_{Rk,c} = k_1 \sqrt{f_{ck,cube}} . h_{ef}^{1.5}$$

$k_1 = 7.2$ (for cracked concrete)

$k_1 = 10.1$ (for non-cracked concrete)

$$N^0_{Rk,p} = \pi . d . h_{ef} . \tau_{Rk}$$

$$S_{cr,N} = 3.h_{ef}$$

$$S_{cr,Np} = 20.d . \left(\frac{\tau_{Rk,ucr}}{7.5}\right)^{0.5} \le 3.h_{ef}$$

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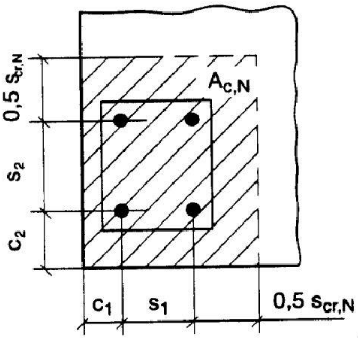
EOTA Design Method for Bonded anchors – Tension Loads

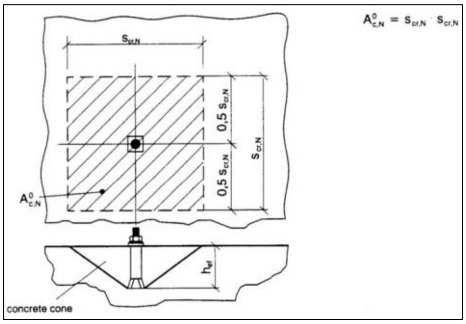
TENSION – Concrete Failure Influence/Actual Areas



$$A_{c,N} = (c_1 + s_1 + 0{,}5\ s_{cr,N}) \cdot (c_2 + s_2 + 0{,}5\ s_{cr,N})$$

if: $c_1 ; c_2 \le c_{cr,N}$

$s_1 ; s_2 \le s_{cr,N}$



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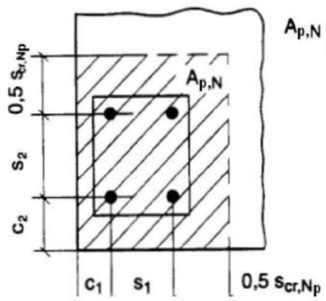
EOTA Design Method for Bonded anchors – Tension Loads

TENSION – Pull-Out Failure Influence/Actual Areas

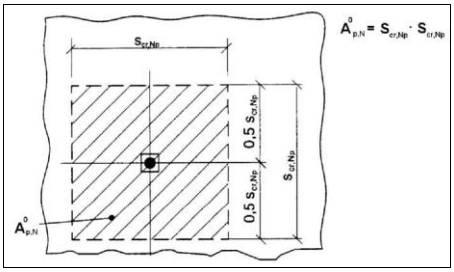
$A_{p,N} = (c_1 + s_1 + 0{,}5\, s_{cr,Np}) \cdot (c_2 + s_2 + 0{,}5\, s_{cr,Np})$

if: $c_1\, ;\, c_2 \leq c_{cr,Np}$

$s_1\, ;\, s_2 \leq s_{cr,Np}$



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



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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

$$\Psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0$$

Eccentricity

$$\Psi_{ec,N} = \frac{1}{1 + \frac{2e_N}{S_{cr,N}}} \leq 1.0$$

NOTE: The influence factors for "edge distance" and "eccentricity" varies for different modes.

Anchor Group

$$\Psi_{g,Np} = \Psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0.5} \cdot \left(\Psi^0_{g,Np} - 1\right) \geq 1.0$$

s = mean value of all spacings

$$\Psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right) \cdot \left(\frac{d.\tau_{Rk}}{k.\sqrt{h_{ef}}.f_{ck,cube}}\right)^{1.5} \geq 1.0$$

Actual member depth

$$\Psi_{h,sp} = \left(\frac{h}{h_{min}}\right)^{\frac{2}{3}}$$

$$1 \leq \Psi_{h,sp} \leq \left(\frac{2.h_{ef}}{h_{min}}\right)^{\frac{2}{3}}$$

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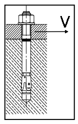
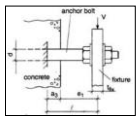
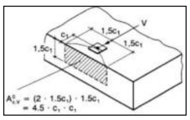
EOTA Design Method for Bonded anchors– SHEAR Loads



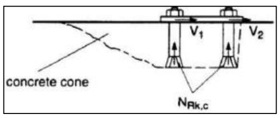
STEEL – Without lever arm



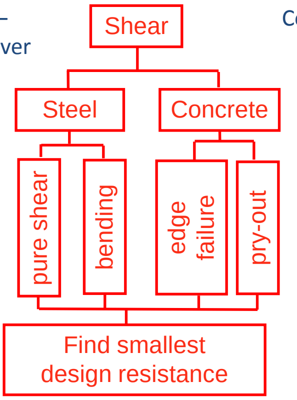
STEEL – with lever arm



Concrete Edge



PRY-OUT



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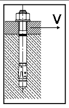
EOTA Design Method for Bonded anchors– SHEAR Loads

- **Shear load without lever arm**

$$V_{Rk,s} = 0.5.A_s.f_{uk}$$

Characteristic Ultimate steel strength

Stressed Area of anchor



- **Shear load with liver arm**

$$V_{Rk,s} = \frac{\alpha_m.M_{Rk,s}}{\ell}$$

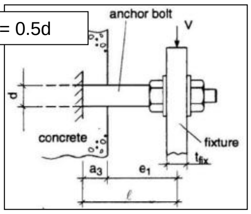
$$M_{Rk,s} = M^0_{Rk,s}(1 - N_{sd} / N_{Rd,s})$$

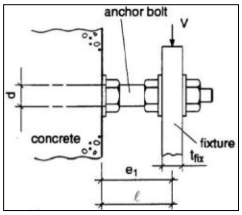
$$N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$$

$$N_{sd} = \text{Design Tension Load}$$

$$M^0_{Rk,s} = 1.2.W_{ef}.f_{uk}$$

$a_3 = 0.5d$





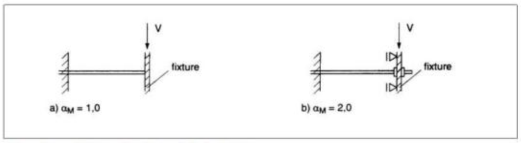


Figure 4.9 Fixture without (a) and with (b) restraint

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EOTA Design Method for Bonded anchors– Shear Loads

$$V_{Rk,c} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \Psi_{s,V} \cdot \Psi_{ec,V} \cdot \Psi_{re,V} \cdot \Psi_{h,V} \cdot \Psi_{\alpha,V}$$

Direction of loading

Correction factor for $A_{c,V}$/ $A^0_{c,V}$ for member thickness “h”

Edge influence due to further edges

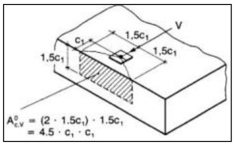
Eccentricity

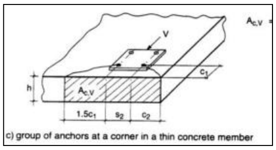
Type of Reinforcement

$$V^0_{Rk,c} = k_1 . d^{\alpha} . h^{\beta}_{ef} . \sqrt{f_{ck.cube}} . c_1^{1.5}$$

$$\alpha = 0.1 \left(\frac{h_{ef}}{c_1} \right)^{0.5}$$

$$\beta = 0.1 \left(\frac{d}{c_1} \right)^{0.2}$$





k_1 = 1.7 for cracked concrete

k_1 = 2.4 for non-cracked concrete

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EOTA Design Method for Bonded anchors– Shear Loads

The lowest value of the following

$$V_{Rk,cp} = k.N_{Rk,p}$$

$$V_{Rk,cp} = k.N_c$$

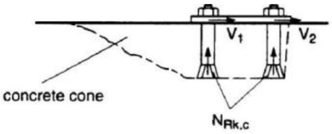
Value of k is taken from the issued ETA

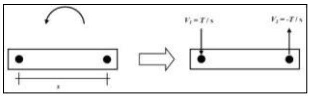
or

for anchors that fail by concrete cone

$k = 1$ (for $h_{ef} < 60$mm)

$k = 2$ (for $h_{ef} \geq 60$mm)





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 in to account the influences of both, edge as well as spacing distances.

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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

$$\Psi_{ec,V} = \frac{1}{1 + \frac{2e_V}{3c_1}} \leq 1.0$$

$\Psi_{re,V}$ Type of Reinforcement

$= 1.0$ (non-cracked concrete and cracked concrete without edge reinforcement)

$= 1.2$ (cracked concrete with straight edge reinforcement $\geq \phi 12$mm)

$= 1.4$ (cracked concrete with edge reinforcement and closely spaced stirrups, a ≤ 100mm)

Correction factor for $A_{c,V}/A^0_{c,V}$ for member thickness "h"

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

Direction of loading $\alpha_V \leq 90°$

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

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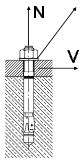
EOTA Design Method for Bonded anchors– Combined Loads



Find smallest design resistance

Load combination

Find smallest design resistance

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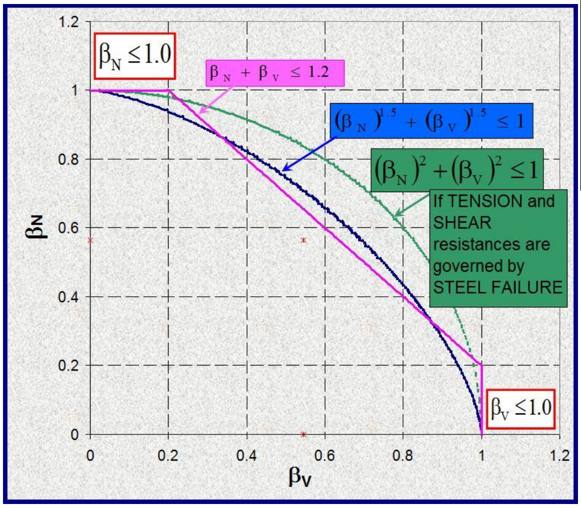
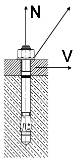
EOTA Design Method for Bonded anchors– Combined Loads



$$\beta_N = \frac{N_{Sd}}{N_{Rd}}$$

$$\beta_V = \frac{V_{Sd}}{V_{Rd}}$$



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

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FAILURE EXAMPLES

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Anchor material failure in shear

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Base material failure in tension

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Anchor pullout failure in tension

Anchors were completely pulled out as the tank tumbled down during the earthquake.

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Anchor pullout failure in tension

Chemical anchors were completely pulled out during an earthquake.

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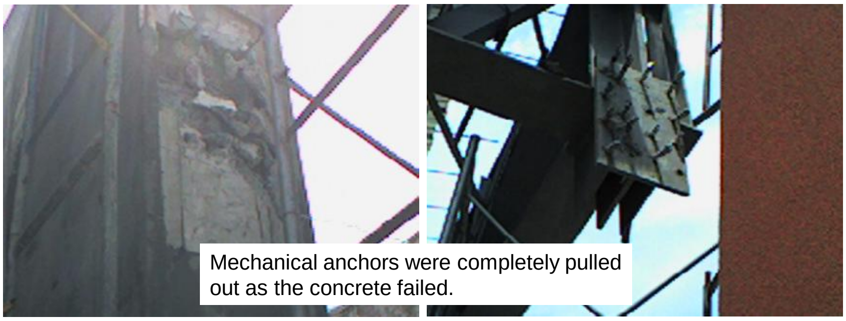
Anchor pullout failure in tension



Mechanical anchors were completely pulled out as the concrete failed.

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Base material failure in shear

Base material cracking as a result of a relatively small edge distance.

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11. Questions and Answers