BEST PRACTICE SPECIFICATION, DESIGN AND INSTALLATION FOR POST-INSTALLED ANCHORS IN SAFETY-CRITICAL APPLICATIONS.

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ABSTRACT: Post-installed anchors are commonly used in safety-critical applications in the building industry and large infrastructure projects. Failure of these types of anchors has the potential to risk human lives and have considerable economic impacts. Factors commonly contributing to the failure of fasteners include limited or no product prequalification, poor specification of products and improper product substitution, poor design and understanding of performance limitations of fasteners, and poor quality installation practice. Such failures are largely avoidable through a safety framework in product selection, design and installation of anchors. This paper discusses the new Standards Australia Technical Specification TS 101:2015 which is the first Australian design guideline providing deemed-to-satisfy provisions for the design of fastenings to concrete, and the AEFAC Installer Certification Program that has been developed to train and equip installers with necessary knowledge and skills to perform installation at the highest level. Collectively, these initiatives form the safety framework for product prequalification, design and installation of fastenings to concrete for safety-critical applications in Australia.

KEYWORDS: post-installed, anchors, safety-critical, specification, design, installation

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1 INTRODUCTION

Post-installed anchors are widely used in the building industry and large infrastructure projects as they provide flexibility for fixture alignment in substrates, generally concrete or masonry. Examples of common applications include fixings of balustrades on bridges, connections of steel columns to concrete footings and connections of structural steel floors to precast concrete cores. In the past, failures have occurred due to insufficient knowledge and awareness in product specification and substitution, design and installation of post-installed anchors. The Australian Engineered Fasteners and Anchors Council (AEFAC) which is a collaboration between industry and academia was formed in 2012 to enhance the safety, specification, selection, design and installation of structural anchors and fasteners for the Australian construction industry.

Prior to the formation of AEFAC, the industry was fragmented; different terminology, evaluation procedures for products and design guidelines existed among suppliers, making selection of a fastener confusing to engineers and potentially dangerous to the end user. Ultimately, there was no assurance about safety standards for the consumer. In an effort to compensate for the uncertainties, engineers introduce large safety margins introducing unnecessary inefficiencies that create a burden on projects and result in costly designs.

Frequent construction problems, failures and fatalities have been encountered in Australia and other similar economies such as in Europe and the US when no guidance for safe design was available. The European and American markets have responded to catastrophic failures by introducing regulation to protect life safety. This paper outlines the recent developments by AEFAC to mitigate such failures by developing a safety framework in enhancing the specifications, design requirements and installation of anchors through the SA TS 101:2015 and AEFAC Installer Certification Program.

2 DESIGN AND MATERIALS

2.1 DESIGN

The new design provisions for fastenings to concrete for use in Australia are now available as the Standards Australia Technical Specification SA TS 101:2015 “Design of post-installed and cast-in fastenings for use in concrete” [1]. This document was instigated by AEFAC and developed by an expert committee. The SA TS 101 is referenced in the National Construction Code (NCC) 2016 providing deemed-to-satisfy provisions for design of safety-critical fasteners (refer to NCC Volume One – Clause B1.4(b)(iii) [2] and NCC Volume Two – Clause 3.11.6(f)(iii) [3]). In Australian practice a fastener installed in concrete may be referred to as an ‘anchor’, such as ‘mechanical anchor’ and ‘chemical anchor’.

Figure 1 demonstrates the compliance path for NCC; by following the design guidelines outlined in the SA TS 101, an engineer automatically satisfies the strength requirements of the NCC. The design provisions in SA TS 101 are based on European guidelines which are underpinned by the Concrete Capacity (CC) Method [4]. The SA TS 101 addresses many of the performance requirements of the NCC, but performance requirements such as seismic and fire requirements are not covered yet. These will be covered by further research. For the time being, different manufacturers and suppliers provide alternative solutions to meet most common applications.

Figure 1: Compliance to NCC and SA TS 101

2.1.1 Scope

The SA TS 101 covers the design of post-installed fasteners (chemical and mechanical anchors) and cast-in anchor channels for safety-critical applications. Failure of safety-critical fasteners may cause injury or death to occupants and lead to considerable economic loss. Examples of post-installed fasteners are shown in Figure 2 and a photo of a cast-in anchor channel is shown in Figure 3.

Figure 2: Post-installed fasteners
The SA TS 101 provides guidelines for the determination of forces acting on fasteners, taking into account eccentricity of loading on fasteners and prying forces. The most loaded fastener in tension is identified and designed for. The document also provides guidance for load sharing among fasteners in a group. For example, Figure 4 shows an oblique shear force acting on a group of four fasteners close to an edge without supplementary reinforcement. The component of the shear force acting perpendicular and towards an edge (V cosθ in Figure 4) is distributed to fasteners located closest to the edge therefore only two out of the four fasteners shown in Figure 4 are considered to be effective in resisting concrete edge failure. This corresponds to the case where after installation the post-installed fasteners close to the edge are in contact with the fixture while the fasteners away from the edge are without contact as shown in Figure 5. The fasteners closest to the edge also have lesser capacity compared to those away from the edge. The component of the shear force acting parallel to an edge (V sinθ in Figure 4) is distributed equally among all fasteners in the group.

Other design considerations include influence of concrete edges, influence of a lever arm for shear loading, influence of fixture plate and load resisted by supplementary reinforcement (if present) to be designed in accordance with AS 3600 [5].

Seismic design for fasteners is discussed in an accompanying paper by the authors [6]. The paper presents the procedure required to adapt the European seismic design provisions for fastenings to concrete for adoption in Australia, including how the European seismic performance categories C1 and C2 are relevant to importance levels stipulated in the National Construction Code.

2.1.3 Design for tension

The SA TS 101 provides guidelines to check for various modes of failure under tension loading. Tensile failure modes are illustrated in Figure 6a) to l), with modes i) to l) specific to anchor channels. Failure in supplementary reinforcement, modes g) and h) in Figure 6 is applicable to both post-installed fasteners and cast-in anchor channels. The critical mode of failure producing the lowest design strength will be the one governing the design tensile capacity of the fastener.
2.1.4 Design for shear

Shear failure modes are illustrated in Figure 7a) to m), with modes g) to m) specific to anchor channels. Failure in supplementary reinforcement, modes e) and f) in Figure 7 is applicable to both post-installed fasteners and cast-in anchor channels.

The critical mode of failure producing the lowest design shear strength will be the one governing the design shear capacity of the fastener.

2.1.5 Design for combined actions

Under combined tension and shear loading, a fastener is required to resist design shear load \(V^*\) and design tensile load \(N^*\) simultaneously. For example, the resistance of a post-installed fastener to modes of failure other than steel failure is assessed via the following:

\[
\left( \frac{N^*}{\Phi_i N_{Rk,i}} \right)^{1.5} + \left( \frac{V^*}{\Phi_i V_{Rk,i}} \right)^{1.5} \leq 1
\]

or

\[
\left( \frac{N^*}{\Phi_i N_{Rk,i}} \right) + \left( \frac{V^*}{\Phi_i V_{Rk,i}} \right) \leq 1.2
\]

with \(N^*/\Phi_i N_{Rk,i} \leq 1\) and \(V^*/\Phi_i V_{Rk,i} \leq 1\). \(\Phi_i\) is the capacity reduction factor; \(N_{Rk,i}\) and \(V_{Rk,i}\) are the characteristic tensile and shear strength determined from Section 2.1.3 and 2.1.4. Verification of fastenings with supplementary reinforcement should also be performed. Further details are given in [1].

2.2 PRODUCT PREQUALIFICATION

Product prequalification is one of the major components in the safety framework for anchors where a robust product approval process ensures the product is fit for intended purpose. The SA TS 101 is compatible for use with post-installed fasteners that have been tested and assessed in accordance with the requirements of Appendix B in the document which refers to the testing procedures outlined in European Technical Assessment Guideline, ETAG 001 Part 1 to Part 5 [7] and for cast-in anchor channels that have been tested and assessed in accordance with the requirements of the European Assessment Document (EAD) “Anchor channels”. Anchor products that have been awarded European Technical Assessments (ETAs, formerly European Technical Approvals) automatically satisfy the requirements of Appendix B in SA TS 101. An ETA is a certification that is awarded by EOTA (European Organisation for Technical Assessment) for products that have been
rigorously tested and independently confirmed to satisfy the requirements of ETAG 001 or EAD and demonstrated to be fit for their intended purposes. Products with ETA are eligible to bear a CE mark, meaning European Conformity. The CE mark is a mandatory conforming marking for trade within the European Economic Area. Adaptations are required for some notations in an ETA to be compatible with the SA TS 101 as given in Appendix C of the document.

There are 12 different Option numbers in ETAG 001 for testing of post-installed products in different intended applications such as cracked and uncracked concrete. If an anchor product has not been awarded an ETA or tested in accordance with Appendix B of SA TS 101, its quality cannot be ascertained against NCC performance considerations; hence it is not eligible to be designed using SA TS 101. It should be noted that compliance with SA TS 101 does not automatically cover all NCC requirements.

3 SPECIFICATION

Specification is an integral part of the safety framework for anchor products. Incomplete specification has resulted in the sourcing of incorrect products leading to the collapse of a ceiling in a large teaching hall as shown in Figure 8. The contractor had procured compression-only brackets instead of tension brackets due to partially complete specification. Failure of one bracket resulted in progressive collapse of the ceiling structure. Accurate and complete specification is imperative to prevent failures from happening due to incorrect products being used.

Figure 8: Collapse of suspended ceiling [8]

3.1 AEFAC ENGINEERING GENERAL NOTES

The SA TS 101 recognises the importance of complete and proper specification. Appendix E in the document refers to the AEFAC Technical Note “Guideline for the specification of fastenings in engineering general notes” [9]. The AEFAC Engineering General Notes provides guidelines for specifications of fasteners in engineering drawings to prevent ambiguity and outlines the change management for product substitution. Current standard notes on engineering contract drawings frequently allow the use of ‘equivalent product’ in lieu of the fastener specified by the design engineer. It is recommended that the responsible engineer must be consulted for the approval of an alternate product or for the approval of a revised specification in the event that the fastener cannot be procured or installed as per the original specification. Alternate products must have the appropriate prequalification and design. Figure 9 provides an example of minimum information to be specified in engineering drawings for chemical fasteners. Sample specification text would be:

- 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.

The AEFAC Engineering General Notes [9] covers specification requirements for other types of fasteners such as torque controlled expansion fastener – thick walled and stud type, deformation controlled expansion fastener, concrete screw and cast-in anchor channel.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>Manufacturer’s name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product name</td>
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Anchor rod
- Type [E.g. Threaded rod]
- Diameter [E.g. M12]
- Length (mm) [E.g. 200mm]
- Finish/Casting [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]

Figure 9: Minimum information to be specified for chemical fasteners

4 INSTALLATION

4.1 COMMON PROBLEMS

Installation is a critical aspect in the quality assurance framework for anchor performance to ensure that fasteners can perform as per intended design. In the past, failures have occurred due to poor installation practices leading to unreliable chemical anchor performance. One such example is the Boston Big Dig Tunnel failure which occurred in 2006 where twenty-six tons of concrete from the
suspended concrete ceiling in the I-90 connector tunnel detached as shown in Figure 10. A vehicle was partially crushed, killing a passenger. Examination of failed anchors showed voids in the chemical (up to 70% of total embedment area), chemical failures and defects such as yellowed epoxy and overflowed epoxy. Common problems for installation generally arise due to installers not understanding performance sensitivity of anchors, failure to adhere to manufacturer’s installation instructions and reducing embedment depth when hitting reinforcement during drilling.

![Figure 10: Collapse of Boston Big Dig tunnel ceiling](image)

**Figure 10: Collapse of Boston Big Dig tunnel ceiling** [10]

### 4.2 INSTALLER CERTIFICATION PROGRAM

Installation of post-installed fasteners are largely carried out on an ad-hoc basis by tradespeople without proper training resulting in many incorrect installations as observed by engineers and anchor suppliers in the industry. The AEFAC Installer Certification Program has been developed to promote best practice for installation and to safeguard human lives and is recommended by SA TS 101 [1]. The AEFAC Engineering General Notes [9] also provides recommendation for installation to be performed by an AEFAC certified installer or by a person trained by the manufacturer/supplier of the specified product. The AEFAC Installer Certification Program is based on the American Concrete Institute ACI-CRSI Adhesive Anchor Installer Program [11] which was developed following the Boston Big Dig Tunnel failure, but it has been extended to include mechanical anchors and adapted for Australian practice.

The Installer Certification Program is a one day program consisting of half a day face-to-face training where installers are introduced to the different types of post-installed anchors and their application matrix, mechanics of anchors and failure modes. Installers are made aware of performance considerations for different anchor types and their sensitivity to various parameters. For example, chemical anchors are sensitive to hole cleanliness, temperature and wetness of concrete.

Proper handling and storage conditions for chemical anchors are also an important aspect. Performance of mechanical anchors on the other hand are very sensitive to drilled hole diameter and less sensitive to hole cleanliness as compared to chemical anchors. Installers are also shown proper installation procedures and alerted to common installation problems that have been encountered on site. The Installer Certification Program provides general instructions for commonly used products and additional product-specific training may be warranted.

Figure 11 shows the structure for the AEFAC Installer Certification Program. Upon completion of face-to-face training, installers are required to sit for a written examination with 65 multiple choice questions to be completed within 60 minutes. All assessment material is covered by the AEFAC Installer Training Manual [12]. Installers are also required to complete a practical examination which is a two part process testing the individual’s competence with the installation of chemical anchor systems. Installers are required to assemble tools and equipment for a designated chemical anchor, demonstrate proper drilling and cleaning technique, proper injection technique and correct setting of the anchor component. Part one of the exam tests the ability of installers to install a chemical anchor in a vertical down orientation according to the manufacturers’ installation instructions (MII) and Material Safety Data Sheet (MSDS) (refer to Figure 13) while part two of the exam tests the ability of installers to inject adhesive overhead using a piston plug (refer to Figure 14). A maximum of two trials are permitted for each part of the practical examination. The examiner will advise the installer of a pass/fail outcome and advise on the error(s) made.

Certification will be awarded to installers who pass both the written and practical exams. An AEFAC Certified Installer has demonstrated knowledge and ability to properly install chemical and mechanical anchors as per manufacturer’s installation instructions. An AEFAC Certified Installer Card as shown in Figure 12 is awarded to a certified installer. All AEFAC Certified Installers are listed live on the AEFAC website (www.aefac.org.au).

Recertification is required after a three-year period and after that every five years to ensure that certified installers have the current skills and knowledge.
Figure 11: Structure for AEFAC Installer Certification Program

Figure 12: AEFAC Certified Installer Card

Figure 13: Vertical down installation

Figure 14: Overhead injection

5 CONCLUSIONS

Post-installed and cast-in fasteners are widely used in safety-critical structures. Failures have occurred in the past due to lack of a safety framework in terms of product design, specification and installation. AEFAC was formed as an industry initiative to lift quality and safety standards to prevent failures in the Australian anchor industry.

SA TS 101:2015 is an initiative of AEFAC providing the first design provisions for post-installed and cast-in fasteners in Australia that has been referenced in the 2016 National Construction Code.

Anchor products to be designed with SA TS 101 need to be tested and assessed in accordance with Appendix B of the document to ensure the product is fit for its intended use. Installation of anchor products should be done in accordance with the manufacturer’s installation instructions by installers with the necessary experience and competency. SA TS 101 recommends that an installer’s competency for installation of fasteners in safety-critical applications be demonstrated through the AEFAC Installer Certification Program and/or by specific training from the supplier of the product being installed. The implementation of the Installer Certification Program together with appropriate prequalification and the design of fasteners through the SA TS 101, form a quality assurance system for the anchor industry.

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