Design Guidelines for Post-Installed and Cast-In Anchors in Australia for Safety-Critical Applications

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Abstract: Post-installed and cast-in anchors are commonly used in safety-critical applications in buildings and large infrastructure projects. This paper discusses the new Standards Australia Technical Specification TS 101:2015 which is the first Australian document providing deemed-to-satisfy provisions for the design of fastenings to concrete. TS 101 provides a consistent approach in designing anchors which is aligned with international practice. It also sets the minimum requirements for prequalification of anchors covering both suitability and admissible service conditions. In addition, the paper discusses the overall safety framework for fastenings to concrete which includes installation quality and field testing. Requirements to satisfy the 100 years of design life in road structures are also briefly discussed.

Keywords: post-installed, cast-in, anchor, safety-critical, design, installation.

1. Introduction

Post-installed and cast-in anchors are widely used in safety-critical applications in buildings and large infrastructure projects. Applications are defined as 'safety-critical' when their failure may cause risk to human life and/or have considerable economic loss. Design provisions for fastenings to concrete in safety-critical applications in Australia, TS 101: 2015 has recently been published by Standards Australia [1]. Prior to TS 101, the design of anchor connections and evaluation of anchor products are not regulated with no Australian standards. TS 101 is an initiative of the Australian Engineered Fasteners and Anchors Council (AEFAC). AEFAC (www.aefac.org.au) was formed in 2012 by Swinburne University of Technology and 6 industry partners to enhance the safety, specification, selection, design and installation of structural anchors and fasteners for the Australian construction industry.

This paper provides an overarching discussion of the safety framework for fastenings to concrete which includes product prequalification, design, installation and field testing.

2. Design, Specification and Prequalification

2.1 Scope

The SA TS 101:2015 covers the design of post-installed fasteners (chemical and mechanical anchors) and cast-in anchor channel for safety-critical applications. Examples of post-installed fasteners are shown in Figure 1 and a photo of cast-in anchor channel is shown in Figure 2.

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 is identified and designed for. Guidance for load sharing among fasteners in a group is also provided. For example, Figure 3 shows distribution of shear force acting on a group of fasteners close to an edge. In Figure 3a), the shear force is acting parallel to an edge and is distributed equally among all fasteners in the group. In Figure 3b), the shear force is acting perpendicular and towards an edge and is distributed to fasteners located closest to the edge. Therefore, only two out of the four fasteners shown in Figure 3b) are considered to be effective in resisting concrete edge failure. This takes into account the scenario where after installation the post-installed fasteners close to the edge are in contact with the fixture whilst the fasteners away from the edge are not in contact as shown in Figure 4. The fasteners closest to the edge also have lesser capacity compared to those away from the edge. Hence, it is a conservative approach to design the fasteners closest to edge to resist the shear load perpendicular to edge.

Figure 1: Post-installed fasteners

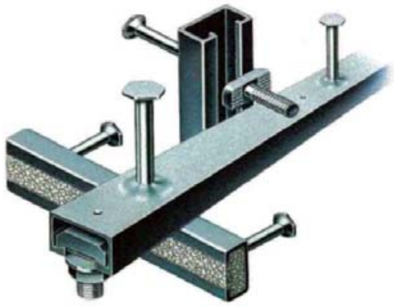
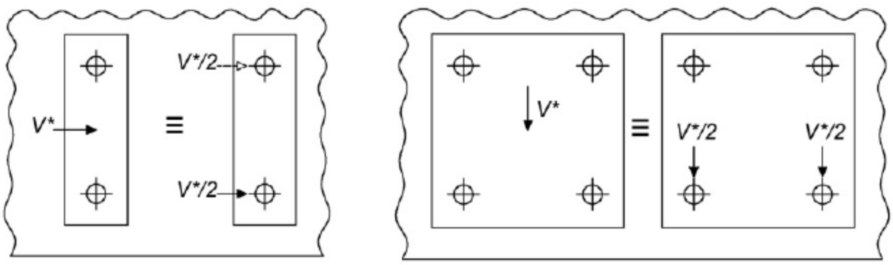


Figure 2: Cast-in anchor channel



(a) TWO FASTENERS WITH A SHEAR LOAD PARALLEL TO EDGE.

(b) FOUR FASTENERS WITH A SHEAR LOAD PERPENDICULAR TO EDGE.

Figure 3: Distribution of shear forces for fasteners in fixtures in close proximity to an edge (1).

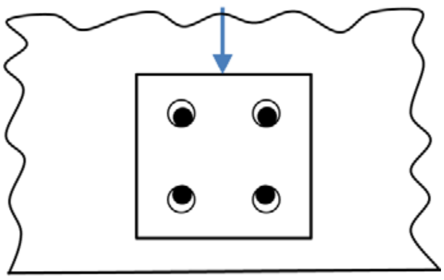


Figure 4: Unfavourable positioning of the fasteners in the holes resisting a shear load acting perpendicular to the concrete edge.

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 3600:2009 [2].

2.2 Exclusions

The SA TS 101 does not cover the design for the following items:

- exposure to fire, durability and seismic actions
- design of fixtures
- 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

Seismic design for fasteners may be adapted from the European seismic design provisions Annex E of ETAG 001 [3], which has seismic performance categories C1 and C2. In Europe, seismic prequalification is not mandatory for all anchors; it is limited to anchors that are used for seismic applications with category C2 requiring a greater level of seismic performance compared to C1.

Alternatively, US seismic provisions may be used as outlined in ACI 355.2 [4] for mechanical fasteners and ACI 355.4 [5] for chemical fasteners. Again similar to Europe, seismic prequalification is only required for anchors used in seismic applications. However, in the US, there is currently only one seismic category which is equivalent to the European category C1 [3].

TS 101 covers the design of shallow embedments with depth not exceeding $20d_{nom}$ for chemical fasteners (where d_{nom} = outside diameter of fastener). For embedments greater than $20d_{nom}$ design of development length to develop yield strength of the bar can be done according to AS 3600:2009 [2] or Eurocode 2 [6]. If designing in accordance with Eurocode 2, the chemical fastener is required to be prequalified to TR 023 [7].

2.3 Product prequalification

Product prequalification is one of the major components in the safety framework for fasteners where a rigorous product approval process ensures the product is fit for the intended purpose. The SA TS 101 is compatible for use with fasteners that have been tested and assessed in accordance with the requirements of Appendix B in the document. For post-installed fasteners, Appendix B refers to the testing procedures outlined in European Technical Assessment Guideline, ETAG 001 Part 1 to Part 5 [3]. For cast-in anchor channels, Appendix B refers to testing procedures outlined in 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 assessed to satisfy the requirements of ETAG 001 or EAD and demonstrated to be fit for their intended purposes. Products with ETA bear a European Conformity mark (CE). The CE mark is a mandatory conforming marking for trade within the European Economic Area. Appendix C of TS 101 lists certain ETA notation and the TS 101 equivalents.

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 a fastener has not been tested in accordance with Appendix B of SA TS 101 and does not have an ETA, it cannot be designed using SA TS 101 as its performance cannot be verified.

2.1 Design

SA TS 101 is referenced in the revised version of the Australian Bridge Design Code, AS 5100.1 due to be published by Standards Australia in 2017. The document covers verification of fasteners loaded in tension, shear and combined actions. Design engineers are required to verify if the concrete will be cracked or uncracked throughout its service life and select the appropriate fasteners for the intended application. The following failure modes in Figure 5 must be checked for tension. Figure 5f to 5j show specific failure modes for an anchor channel. The critical failure mode producing the lowest design strength will be the one governing the design tensile capacity of the fastener.

Similarly, the failure modes in Figure 6 must be checked for shear. Figure 6f to 6m show specific failure modes for an anchor channel. The critical mode of failure producing the lowest design strength will be the one governing the design shear capacity of the fastener.

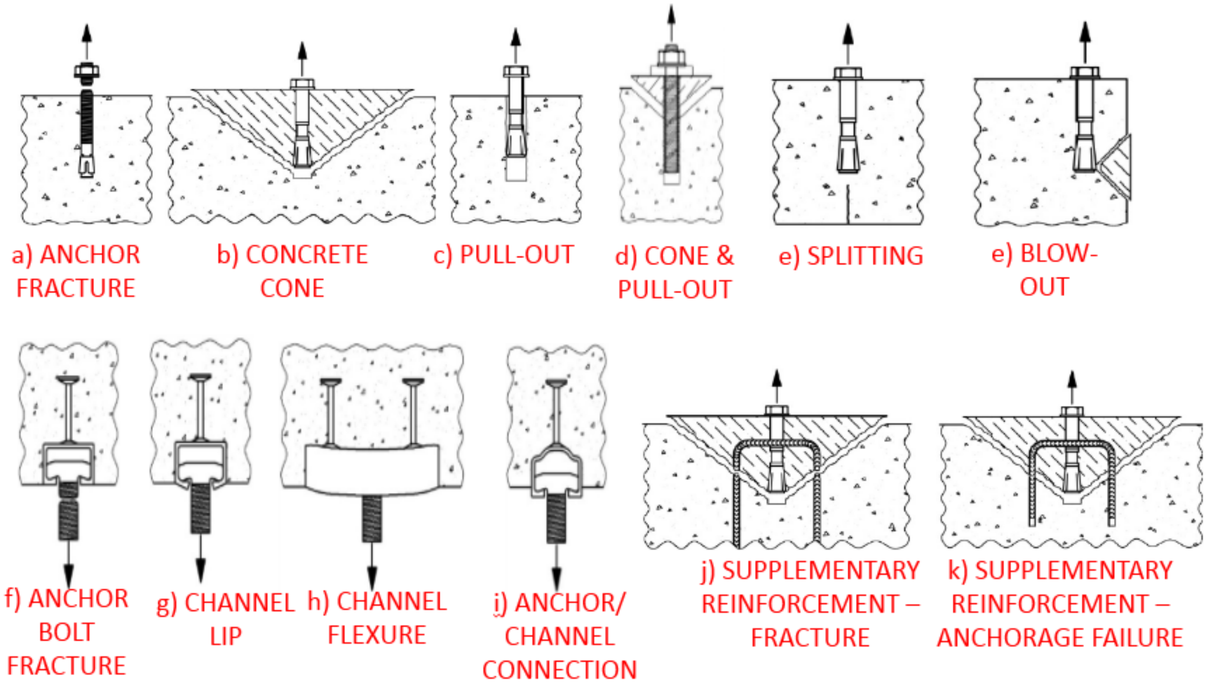


Figure 5: Failure modes in tension

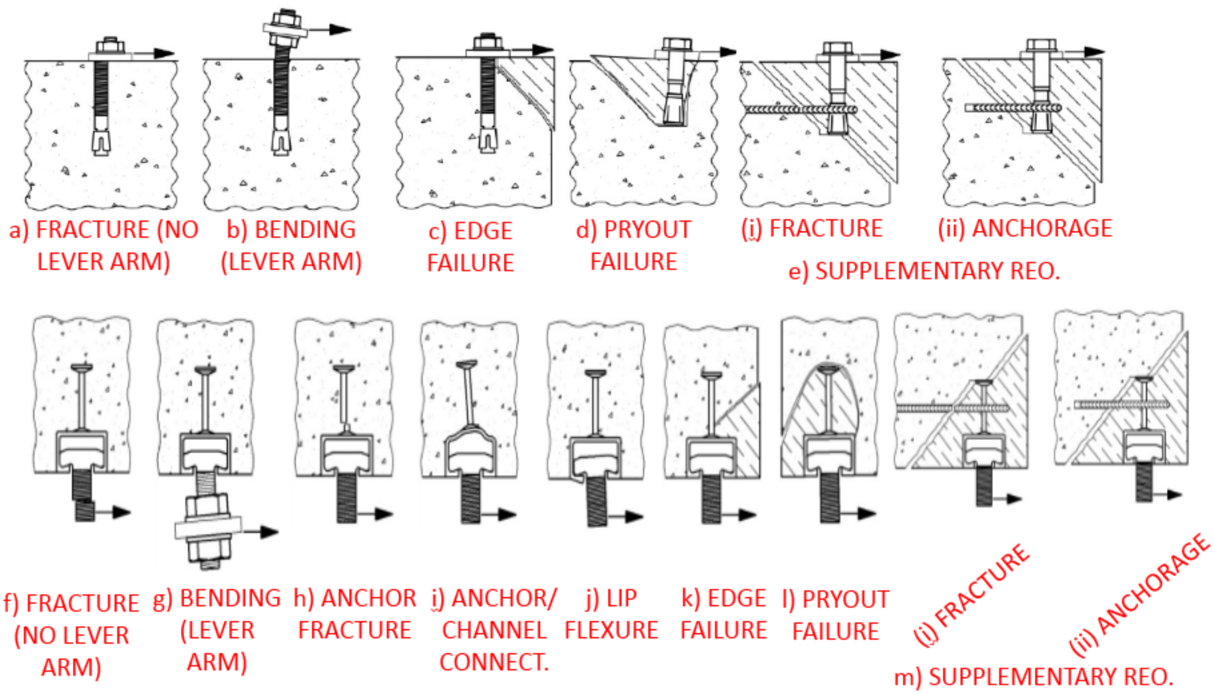


Figure 6: Failure modes in shear

2.2 *Product specification*

Specification is an integral part of the safety framework for fastenings. Poor or incomplete specification has led to major faults in the past where the wrong product has been procured and did not perform in accordance with the intended design. The SA TS 101 recognises the importance of complete and proper specification of anchor products. Appendix E in the document refers to the AEFAC Technical Note “Guideline for the specification of fastenings in engineering general notes” [8]. The AEFAC Engineering General Notes provides guidelines for specification of fasteners in engineering drawings to prevent ambiguity in specifications and outlines change management requirements for product substitution. S standard notes on engineering contract drawings may allow the use of ‘equivalent products’ as an alternative to the fastener specified by the design engineer. It is recommended that the responsible engineer must be consulted for the approval of a product substitution or for the approval of a revised specification in the event that the fastener cannot be procured or installed in accordance with the original specification. Alternate products must have the appropriate prequalification and design. A sample specification text could be as follows:

- The chemical adhesive shall be a (manufacturer name, product name). The anchor rod shall be a M16 x 200 threaded rod, galvanised, steel grade 8.8, installed in a 18mm diameter hole with a 130 mm depth and tightened to a maximum torque of 100Nm using a calibrated torque wrench.
- Cleaning accessories prescribed by the manufacturer’s installation instructions shall be used.

The AEFAC Engineering General Notes [8] covers specification requirements for other types of fasteners such as torque controlled expansion fastener which includes thick walled and stud types, deformation controlled expansion fasteners, concrete screws and cast-in anchor channels.

3. Installation

Proper installation is critical to ensure anchor products can perform in accordance with the intended design. The requirement for training is greater for chemical anchors with deep embedment as the cleaning and injection procedure is more sensitive in the case of substantially deeper holes. Installation of post-installed fasteners is largely carried out on an ad-hoc basis by tradespeople, many without proper training resulting in 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 ensure safety and is recommended by SA TS 101. The revised AS5100.1 also recommends that installation is 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 [9] which was developed following the Boston Big Dig Tunnel failure in 2006, but the program has been extended to include mechanical anchors and modified for Australian practice.

The Installer Certification Program is a full day program consisting of a half day of face-to-face training, followed by a written examination and a practical examination as shown in Figure 7. During the training, 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, mechanical anchors are sensitive to drilled hole diameters while 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. 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.

The written examination consists of 65 multiple choice questions to be completed within 60 minutes. All assessment material is covered by the AEFAC Installer Training Manual [10]. Upon completion of the written examination, candidates are 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 manufacturer's installation instructions (MII) and Material Safety Data Sheet (MSDS) (refer to Figure 8) while part two of the exam tests the ability of installers to inject chemical in an overhead orientation using a piston plug (refer to Figure 9). Each candidate is allowed a maximum of two trials for each part of the practical examination. The examiner will advise the installer of a pass/fail outcome and comment on the error(s) made.

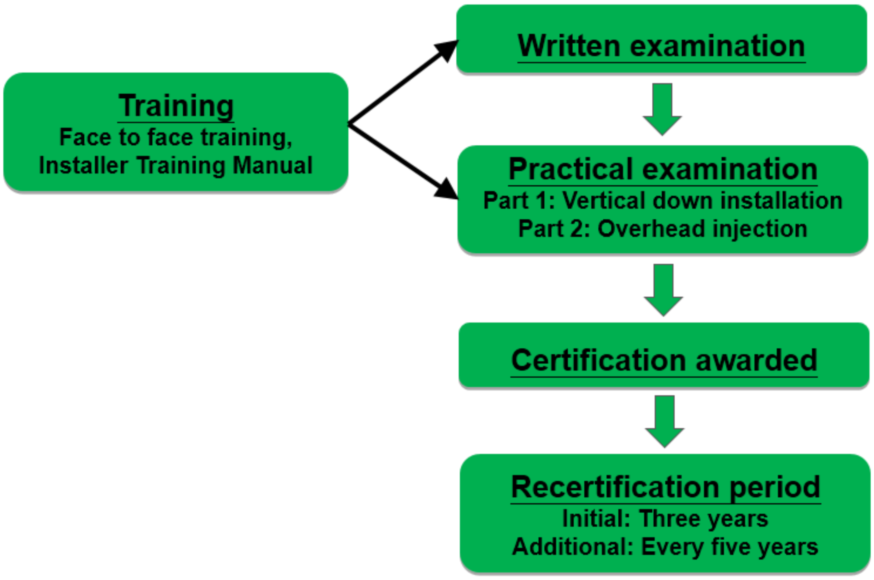


Figure 7: AEFAC Installer Certification Program

Certification is awarded to installers upon passing 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 10 is awarded to a certified installer. All AEFAC Certified Installers are listed 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 8: Vertical down installation

Figure 9: Overhead injection

Figure 10: AEFAC Certified Installer Card

4. Field testing

Site testing may be performed to validate correct installation (proof tests), or to identify the characteristic strength of a fastener in a given substrate (ultimate tests). The performance of anchors in concrete is typically known, thus ultimate tests generally are not warranted in concrete substrates. However, given the complexity of masonry substrates, technical data is generally limited such that site testing is frequently employed to determine the ultimate strength of a fixing for use in masonry substrates.

Site testing for proof tests and ultimate tests requires that the fasteners being tested are installed in accordance with the manufacturer's installation instructions, as well as any supplementary requirements stipulated by the responsible engineer. The AEFAC Technical Notes on site testing, Volume 1 to 4 [11-14] provide best practice recommendations for site testing of post-installed anchors and is in line with international practice recommended by BS 8539 [15] and CFA [16]. Figure 11 provides a summary of site testing requirements.

4.1 Proof test

The purpose of undertaking proof tests is to demonstrate that an anchor has been correctly installed by applying a force equivalent to a multiple of the design capacity of the anchor. It is imperative that the proof test does not damage the anchor as a result of the test. The magnitude of the proof load is at the discretion of the responsible engineer and will be project dependent.

The recommended minimum test sample population is three specimens or 2.5% of the total relevant anchor population, whichever is greater. If a single failure is recorded, the minimum test sample population shall be increased to six test specimens or 5% of the total relevant anchor population, whichever is greater. If two or more test samples fail, all anchors in the relevant anchor population should be tested.

The 'test sample population' is defined as a group of anchors representative of the relevant anchor population, having the same type of anchor, the same base material (that has not experienced different environmental exposure), same installation method and same installation personnel. Where any of these variables change, this group of anchors shall be considered a separate anchor population.

Load regime for proof test is as follows:

- For anchors with ultimate limit state capacities, proof test load (N_p) should not exceed the lesser of the ultimate limit state design capacity of the anchor and 0.7x yield capacity of the anchor to prevent damage to the anchor.
- For anchors with allowable working load capacities, proof test load (N_p) should not exceed 1.5 × allowable working load of the anchor and 0.7x yield capacity of the anchor to prevent damage to the anchor.
- The proof load shall be maintained for a minimum of 30 seconds. The load should not drop more than 10% in that duration.

It should be noted if any visible deformation has occurred during the tests, client should be consulted to determine if detailed deformation measurement is required. In general, visible deformation during a proof test constitutes failure.

4.2 Ultimate test

The objective of the ultimate tests is to determine the allowable strength of the fastening. If ultimate tests are required, they should be performed prior to completion of the fastener selection process to ensure that all project requirements are met.
Scenarios where site testing may be performed are as follows:

i) Manufacturer has a provisional approval for the product to be used in the substrate but performance data is not available.
ii) Fastener has an approval (e.g. ETA) for use in masonry but the type, strength or dimensions of the masonry are outside the scope of the ETA.
iii) Fastener has an approval (e.g. ETA) but the substrate is outside the scope of the ETA, for example edge distance is outside the approval scope.

Ultimate tests are carried out on a sample population of sacrificial fastenings that are considered to be representative of the intended application. This requires a representative substrate, the same type of fasteners that will be used in the project and installation by the same work crew. It may be necessary following testing to make good any substrate damage incurred by the test population.

Ultimate tests are not required for fasteners in concrete provided the product is prequalified in accordance with Appendix B of TS101 and the application falls within the scope of the product’s approval.

If the intended application is beyond the scope of its prequalification (approval), ultimate tests may be performed to establish the allowable strength provided the fastener manufacturer recommends the fastening for use in this specific application. Further guidance is available on the limitations of anchors installed in concrete applications in ETAG 001 [3] and for chemical anchors installed in masonry in ETAG 029 [17].

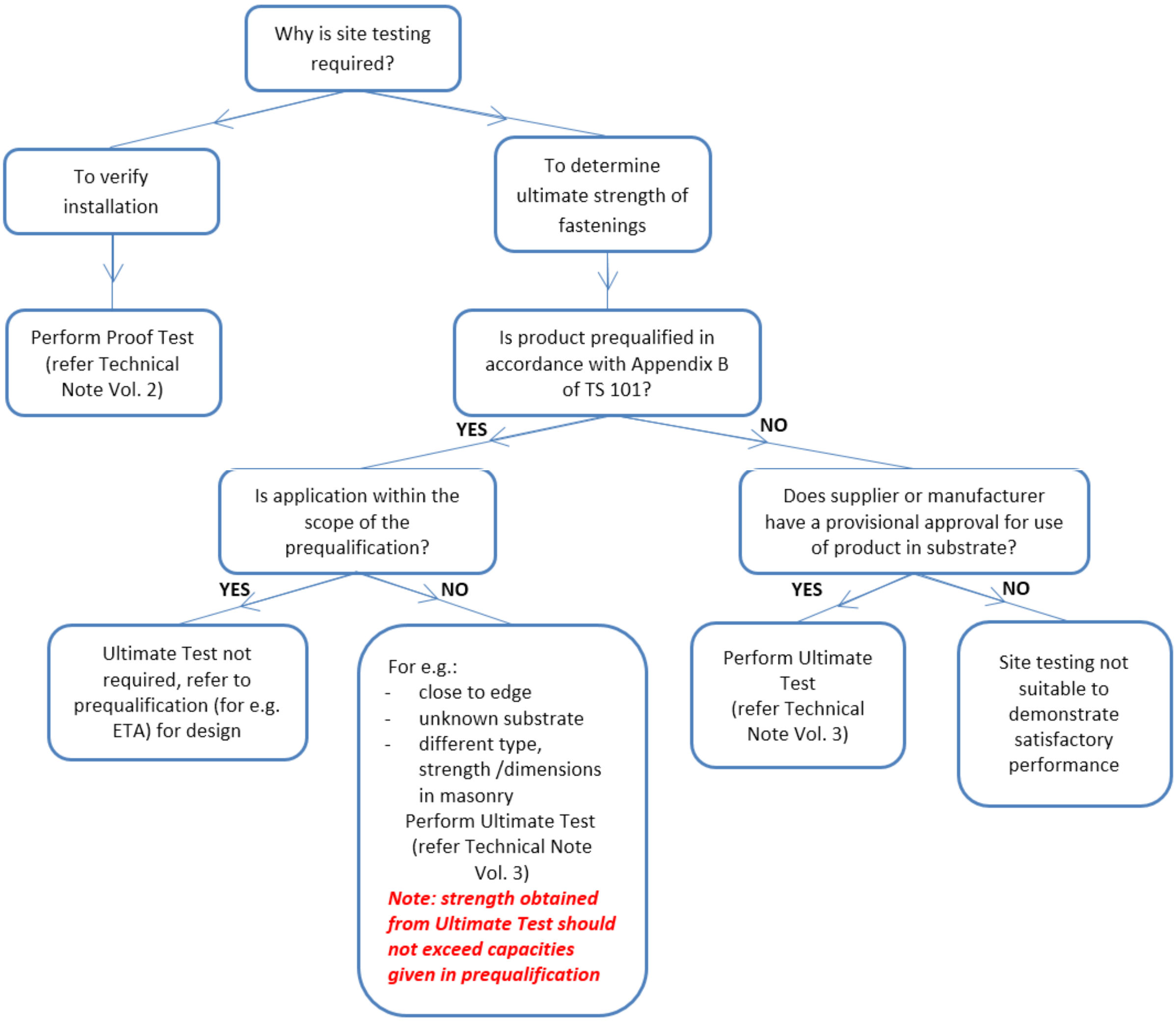


Figure 11. Flow chart for field testing.

5. 100 year design life

The AS 5100 Bridge Design Code [18] requires that road structures, particularly new structures, have a 100-year design life. Anchor products prequalified in accordance with ETAG 001 are generally intended to have a 50-year design life. Anchor suppliers may be able to provide additional data beyond the prequalification information based on proprietary testing or experience. In general, for bonded anchors one of the major concerns is their creep performance under sustained loading over time. Current provisions in TS101 and associated ETAG testing are limited to 50 years. In order to estimate the maximum creep displacement over a longer period, additional testing may be required. One such example is the Legacy Way tunnel in Brisbane [19], where specific testing was conducted for chemical anchors comprising a 20mm rebar installed to a depth of 300mm into steel fibre-reinforced concrete segments. The specimens were placed in an environmental chamber for over a period of 3 months with sustained loading of 125kN at 20˚C +/- 5˚C. The deflection was extrapolated to 100 years in accordance with ETAG 001 Part 5 Section 6.1.1.2 [3] to check for compliance. Studies by Eligehausen et al. [20] on the behavior of chemical fasteners under sustained load found that the projection of displacements from a relatively short time to the intended service lifetime using current formulation in ETAG 001 is conservative. It is proposed that for a 100-year design life, the projected displacement should not exceed the mean value of displacements at loss of adhesion in the corresponding reference tests at normal ambient temperature or maximum long-term temperature. In addition to satisfying this maximum limit, the fastening system should also satisfy durability requirements which would depend on the environmental conditions for the nominated application.

6. Conclusions

AEFAC was founded in 2012 as an industry initiative to lift quality and safety standards to prevent failures in the Australian anchor industry. The SA TS 101:2015 is an initiative of AEFAC providing the first design provisions for post-installed and cast-in fasteners in Australia. Proper design, specification and installation form the safety framework for the anchor industry. The AEFAC Installer Certification Program was introduced to equip installers with knowledge and skills on best practice installation.

Research is currently in progress to identify future modifications to TS 101 to include the design of fastenings to concrete for seismic actions within its scope and to provide guidance on design of deep embedment based on development length calculations in AS 3600 and Eurocode 2. Whilst current anchor prequalification with ETA is only for 50 years, current research has shown that extrapolating displacements over a relatively short time to the intended service life time using current formulation in ETAG 001 can be considered to be conservative.

7. Acknowledgements

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