TECHNICAL NOTE

AEFAC
Australian Engineered Fasteners and Anchors Council

AEFAC - TN01

DESIGN CONCEPTS FOR POST-INSTALLED AND CAST-IN FASTENERS

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1. Scope

The purpose of this technical note is to summarise the two main design methods that may be encountered in the Australian fastener industry. This technical note provides a better understanding of the design methods that are commonly presented in technical literature from different manufacturers/suppliers.

2. Notation

E_d = Design action (load)
F = Factor of safety
F_c = Factor of safety for concrete
F_s = Factor of safety for steel
R_u = Characteristic resistance (strength)
R_d = Design resistance (strength)
$N_{u,c}$ = Nominal strength of a single fastener to concrete cone failure
N^* = Design tensile force
WLL = Working Load Limit
$Ø$ = Capacity reduction factor
γ = Partial safety factor
γ_L = Partial safety factor for loads
γ_M = Partial safety factor for material

3. Terminology

The following terminologies and definitions are used in this Technical Note. Please refer to AEFAC Fastener Dictionary [1] for additional terminologies and definitions.

Action: the cause of stress or deformations in a structure

Allowable working load: See "Working Load Limit"

Anchor: see "Fastener"

Base material: material in which the anchor is installed

Capacity reduction factor: a factor used to multiply the nominal capacity to obtain the design capacity

Characteristic strength: value of the material or connection strength, as assessed by a standard test that is generally exceeded by 95% of the material or connection (lower 5 percentile value of strength)

Design action or design load: the combination of the nominal actions or loads and the load factors specified in AS/NZS 1170.0 [2], AS/NZS 1170.1 [3], AS/NZS 1170.2 [4], AS/NZS 1170.3 [5], AS 1170.4 [6] or other standards

Design capacity: the product of the characteristic capacity and the capacity reduction factor

EOTA: European Organisation for Technical Approvals is the organisation responsible for developing ETAGs in line with mandates issued by the European Commission

ETA: European Technical Assessment (ETA) is the key document for specifiers which confirms the fitness for the intended use and contains details of the fastener specification, performance characteristics, design method and application limits (formerly European Technical Approval)

Factor of safety: the ratio between nominal strength and nominated strength and represents all uncertainties in the Working Stress Design approach

Fastener: a manufactured device that connects a fixture to base material

Global safety factor: the margin for safety including environmental conditions, uncertainties in loads, and uncertainties associated with the strength of the fixture

Limit State: any limiting condition beyond which the structure ceases to fulfil its intended function

Load: an externally applied force

Nominal capacity: the capacity of a member or connection typically computed using a design model not including capacity reduction factors

Partial safety factor: a safety factor accounting for unknown variability in either the loads or strength

Safe working load: see "Working load limit"

Strength reduction factor: see "Capacity reduction factor"

Working load limit: the maximum load that can be applied without the strength and stability requirements being exceeded. Also known as safe working load, allowable working load, maximum rated load, and permissible working load

Working Stress Design: a method of proportioning structural members and connections, such that elastically computed stresses produced in the members by nominal loads do not exceed specified allowable stresses. Also known as allowable stress design or permissible stress design

4. Working stress design method

The Working Stress Design (WSD) method has been used in practice for many years and is a simple methodology for producing a rapid solution. A factor of safety is used to account for uncertainties and ensures the structure remains well within the elastic range. However, the method has many limitations and has been superseded by the more rational and accurate reliability-based Limit State Design. The method assumes any variability in the loading or strength is the same for different design scenarios.

The Working Stress Design may be expressed as follows:

$$\text{Working Load Limit (WLL)} \leq R_u/F \qquad (1)$$

where

R_u = Characteristic strength

F = Factor of safety

Typical values for the factor of safety adopted for fastener design are F_c = 3.0 (concrete) and F_s = 2.5 (steel).

A similar expression for the WLL appears in some product literature as follows:

$$\text{Recommended strength} = \frac{R_u}{\gamma_L \times \gamma_M} \qquad (2)$$

where

R_u = Characteristic strength

γ_L = Partial safety factor for loads

γ_M = Partial safety factor for materials

The typical value for γ_L is 1.4 and the value of γ_M is dependent on mode of failure. The characteristic strength, R_u, may be determined from minimum or mean test values, depending on the method used, with a statistical reduction (sampling factor determined from statistical measures of the sample population) to account for variability based on sample size.

5. Limit state design method

Limit State Design (LSD) methodology is a rational approach to engineering design and addresses some of the limitations of the Working Stress Design methodology. This methodology is based on the identification of the statistical load and strength distribution curves, as well as the acceptable probability of failure. LSD has gained favour in international guidelines for post-installed fastener prequalification [7-10] and design [11-13]. Further, LSD has also been adopted throughout the Building Code of Australia [14].

Limit State Design may be divided into ultimate limit state design and serviceability limit state design.

Ultimate limit state design is concerned with failure of the system or structure. Serviceability limit state design is concerned with the structure not being able to achieve its functional requirements which typically include limiting deformation, vibrations and cracking in concrete structures.

The limit state design concept for fasteners requires that the design actions (loading in tension, shear and combined actions) do not exceed the respective design resistance (strength), expressed as:

Design action ≤ Design resistance (strength)

$$E_d \leq R_d \tag{3}$$

where

E_d= Design action (load)

R_d= Design resistance (strength)

= $\emptyset R_u$

$\emptyset$ = Capacity reduction factor

R_u = Characteristic strength

Figure 1 illustrates the concept of factoring loads and strength to ensure Equation (3) is satisfied and the design is adequate. Figure 2 contrasts the LSD and WSD methods.

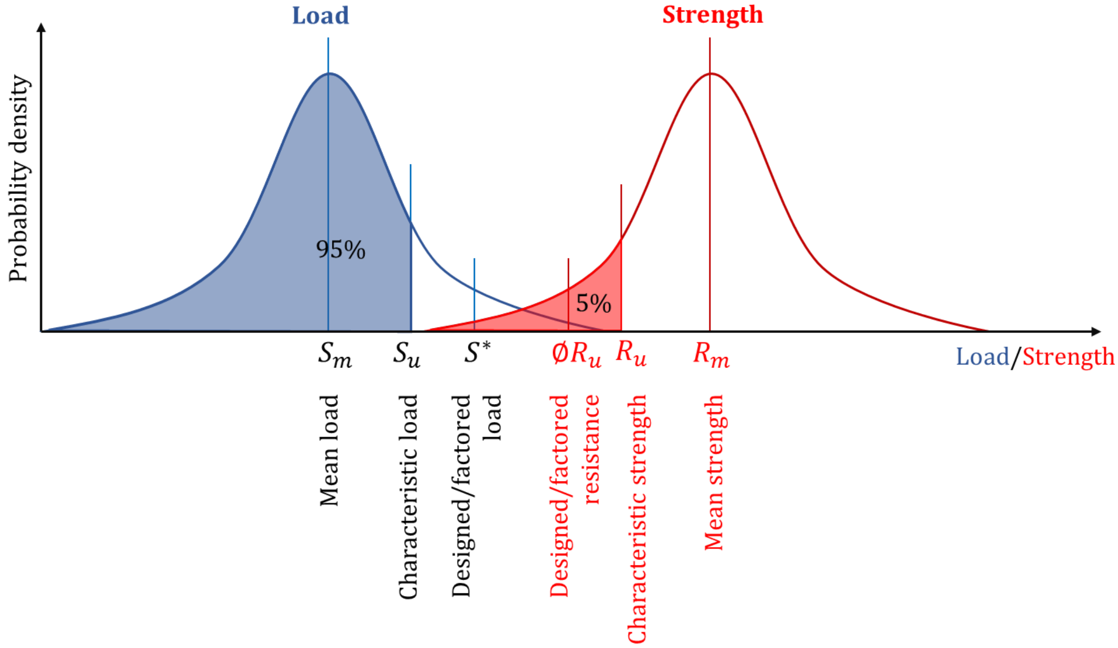

Figure 1: Probability distribution for applied load and strength.

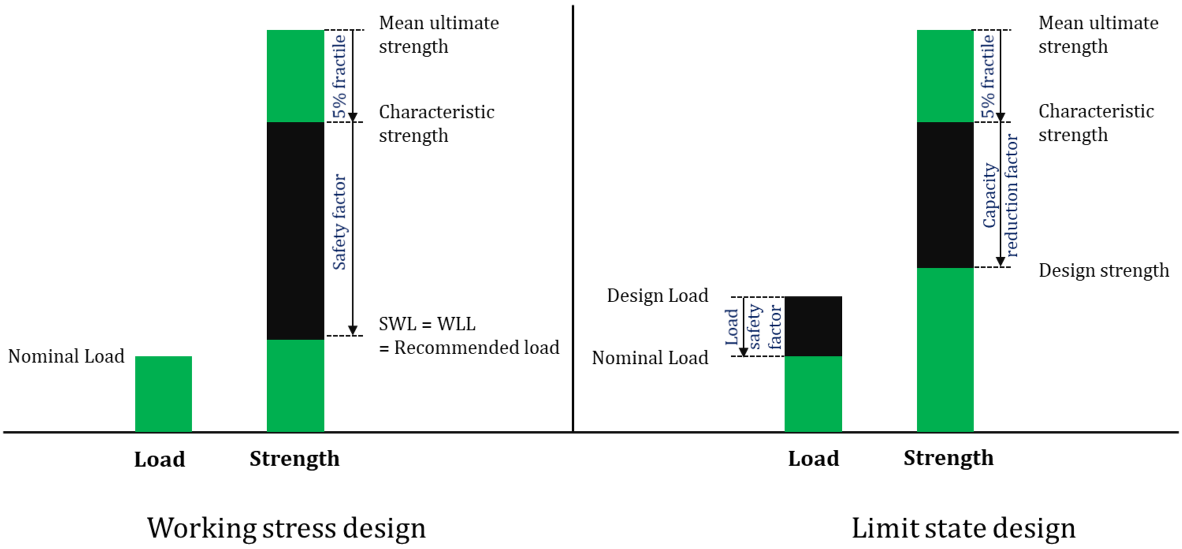

Figure 2: Illustration of global safety factor method and partial safety factor method.

The LSD method is generally applied as either the Load and Resistance Factor Design (LRFD) or the partial safety factor method, described below.

5.1. Load and Resistance Factor Design (LRFD) Method

In Australia, Europe and the U.S., the design methodology for fasteners is based on the Concrete Capacity (CC) method which requires consideration of each possible failure mode of the base material and steel component. This method is based on the LSD methodology.

As an example, when considering tension, the factored (design) tensile force applied to a fastener, N^*, must not be greater than the design strength for concrete cone failure, $\emptyset N_{u,c}$:

Factored tensile force ≤ Design capacity (concrete cone failure)

$$N^* \leq \emptyset N_{u,c} \quad (4)$$

where

$\emptyset$ = Capacity reduction factor

$N_{u,c}$ = Nominal strength of the fastener to concrete cone failure accounting for effects such as edge distance, spacing, concrete strength, etc.

This procedure must then be repeated for all possible failure modes, with the lowest capacity being decisive for the fastener strength.

5.2. Partial safety factor method

The Partial Safety Factor method is almost identical to the LRFD method and is commonly applied to fasteners qualified with a European Technical Assessment (ETA). The characteristic strength is divided by the partial safety factors, γ which are approximately the reciprocal of capacity reduction factors. Equation (5) demonstrates the relationship between the design strength (R_d) and characteristic strength:

$$R_d = {R_u}/{\gamma_M} \tag{5}$$

where

R_u = Characteristic strength

γ_M = Partial safety factor dependent on mode of failure

The characteristic strength issued in an ETA has a reduction included to account for environmental conditions such as durability, creep, freeze/thaw and application conditions. The mode with the lowest characteristic strength is decisive.

6. References

[1] AEFAC, Technical Note, "AEFAC Fastener Dictionary," Australian Engineered Fasteners and Anchors Council. www.aefac.org.au.

[2] Standards Australia, AS/NZS 1170.0: Structural design actions - General principles, SAI Global, Sydney, 2002

[3] Standards Australia, AS/NZS 1170.1: Structural design actions - Permanent, imposed and other actions, SAI Global, Sydney, 2002

[4] Standards Australia, AS/NZS 1170.2: Structural design actions Wind actions, SAI Global, Sydney, 2011

[5] Standards Australia, AS/NZS 1170.3: Structural design actions - Snow and ice actions, SAI Global, Sydney, 2003

[6] Standards Australia, AS 1170.4: Structural design actions Earthquake actions in Australia, SAI Global, Sydney, 2007

[7] European Assessment Document, EAD 330232, "Mechanical fasteners for use in concrete", European Organization for Technical Approval.

[8] European Assessment Document, EAD 330499, "Bonded fasteners for use in concrete", European Organization for Technical Approval.

[9] American Concrete Institute 355.2–07, “Qualification of Post-Installed Mechanical Anchors in Concrete (ACI 355.2-07 and Commentary)”, American Concrete Institute Committee 355

[10] American Concrete Institute 355.4–11, “Qualification of Post-Installed Adhesive Anchors in Concrete (ACI 355.4-11 and Commentary)”, American Concrete Institute Committee 355

[11] Standards Australia, AS 5216: Design of post-installed and cast-in fastenings in concrete, SAI Global, Sydney, 2018

[12] EN 1992-4, “Design of fastenings for use in concrete”, CEN European Committee for Standardization, 2018

[13] American Concrete Institute 318 – 19, “Building Code Requirements for Structural Concrete and Commentary”, American Concrete Institute Committee 318

[14] Building Code of Australia, Vol. 1 and 2, National Construction Code, Australian Building Codes Board, 2019

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