TECHNICAL NOTE

AEFAC
Australian Engineered
Fasteners and Anchors Council

AEFAC – TN14

DESIGN OF FASTENERS UNDER FATIGUE LOADING

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1. Scope

Provision for prequalification and design of fasteners under fatigue loading is currently not covered in AS 5216 [1].

This Technical Note provides guidelines for the prequalification and design of fasteners under pulsating tension load, pulsating and alternating shear load and combinations thereof.

This Technical Note is applicable for post-installed fasteners and cast-in headed fasteners.

This Technical Note does not cover

1. Fasteners qualified for use in connecting statically indeterminate non-structural systems
2. Fastenings with annular gaps*
3. Fasteners with shear loading with lever arm
4. Fasteners with possible loosening of nuts and screws†.

To use the design provisions of this Technical Note, fasteners shall be prequalified in accordance with EAD 330250 [2]. The resistance and condition of use for fasteners under fatigue loading provided in pre-qualification report shall be used. The transfer of resistance values to similar fasteners shall not be done as only a slight change can lead to different behaviour.

The basis of this Technical Note is EN1992-4 [3] and EOTA TR-061 [4].

<u>Note:</u>
The verification of the fasteners for fatigue cyclic load consists of both static and cyclic loading. The verification of the fasteners under static loading should be carried out in accordance with AS 5216. This Technical Note covers the verification of the fasteners for fatigue cyclic loading only.

Fatigue verification is recommended in the following conditions:

1. *Expected pulsating tension load cycles on the fastener ≥ 1000*
2. *Alternating/pulsating shear load cycles on the fastener ≥ 100*
3. *Stress due to climatic variation in the lowest stressed fastener > 100 MPa in tension and > 60MPa in shear.*

* If the fastener is loaded in tensile loads only, the annular gap may not be required to be filled.
† This TN assumes there is a continuous prestressing force throughout the life of the fasteners.

2. Terminology

Please refer to AEFAC Anchor Dictionary [5] for additional terminologies and definitions.

3. Notation

The symbol used in this document, including their definitions, are listed below.

Unless specified otherwise, nominal units for length are millimetres and nominal units for material strength are megapascals.

Symbol		Definition
$\phi_{F,fat}$	=	Capacity reduction factor for fatigue loading, given in product prequalification report
$\phi_{Mc,fat}$	=	Capacity reduction factor for concrete cone failure, concrete splitting failure, concrete pry out failure and concrete edge failure under fatigue loading
$\phi_{Mp,fat}$	=	Capacity reduction factor for pull-out failure under fatigue loading
$\phi_{Ms,N,fat}$	=	Capacity reduction factor for steel failure in tension under fatigue loading
$\phi_{Ms,V,fat}$	=	Capacity reduction factor for steel failure in shear under fatigue loading
$\psi_{F,N}$	=	reduction factor applied to the tension resistance to account for the unequal distribution of the tension load acting on the fixture to the individual fasteners of a group
$\psi_{F,V}$	=	reduction factor applied to the shear resistance to account for the unequal distribution of the shear load acting on the fixture to the individual fasteners of a group
ΔN^*_{fk}	=	Peak to peak amplitude of the fatigue tensile action
$\Delta N_{Rk,s}$	=	fatigue resistance, tension, steel, given in the prequalification report
$\Delta N_{Rk,c}$	=	fatigue resistance, tension, concrete cone for $2x10^6$ load cycles
$N_{Rk,c}$	=	Calculated from AS 5216 Section 6
$\Delta N_{Rk,p}$	=	fatigue resistance, tension, pull-out, given in prequalification report
$\Delta N_{Rk,sp}$	=	fatigue resistance, tension, concrete splitting for $2x10^6$ load cycles
$N_{Rk,sp}$	=	Calculated from AS 5216 Section 6
$\Delta N_{Rk,cb}$	=	fatigue resistance, tension, concrete blow-out for $2x10^6$ load cycles
$N_{Rk,cb}$	=	Calculated from AS 5216 Section 6
ΔV^*_{fk}	=	Peak to peak amplitude of the fatigue shear action

$\Delta V_{Rk,s}$	=	fatigue resistance, shear, steel, given in the prequalification report
$V_{Rk,c}$	=	Calculated from AS 5216 Section 7
$\Delta V_{Rk,cp}$	=	fatigue resistance, shear, concrete pry-out for $2x10^6$ load cycles
$V_{Rk,cp}$	=	Calculated from AS 5216 Section 7
$\Delta V_{Rk,c}$	=	fatigue resistance, shear, concrete cone for $2x10^6$ load cycles
$V_{Rk,c}$	=	Calculated from AS 5216 Section 7

4. Pre-qualification and design method

If a fastener is subjected to fatigue cyclic loading, the failure occurs after number of cycles significantly lower than static failure load. Thus, it is not only the characteristic resistance which govern the design. The number of cycles, pulsating/alternating loading and load level govern in designing the fasteners. Refer to Figure 1 for the typical fatigue loading.

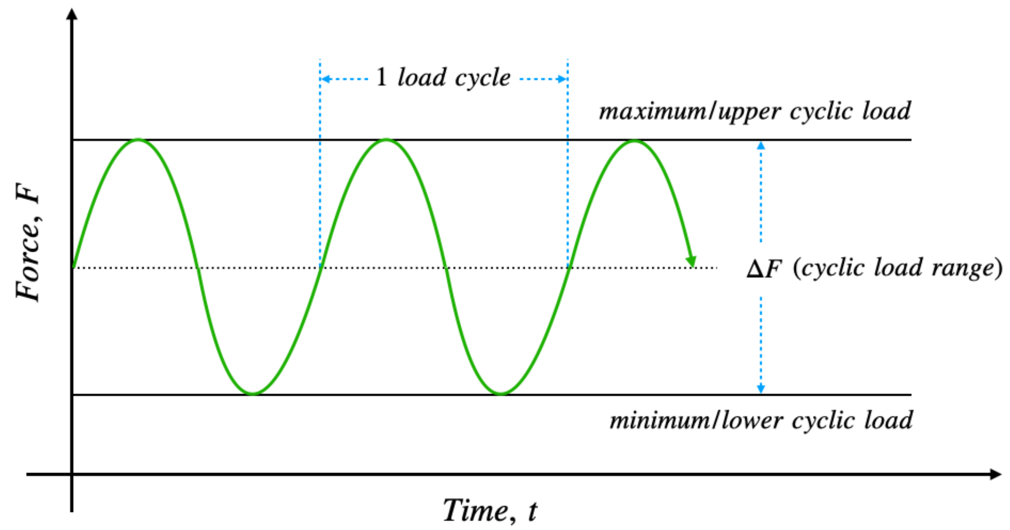

Figure 1: Definition of fatigue loads

A typical S-N curve, also known as Wohler curve [6], is shown in Figure 2, which shows the relationship between the stress (or load) and number of cycles is used in the design of fasteners.

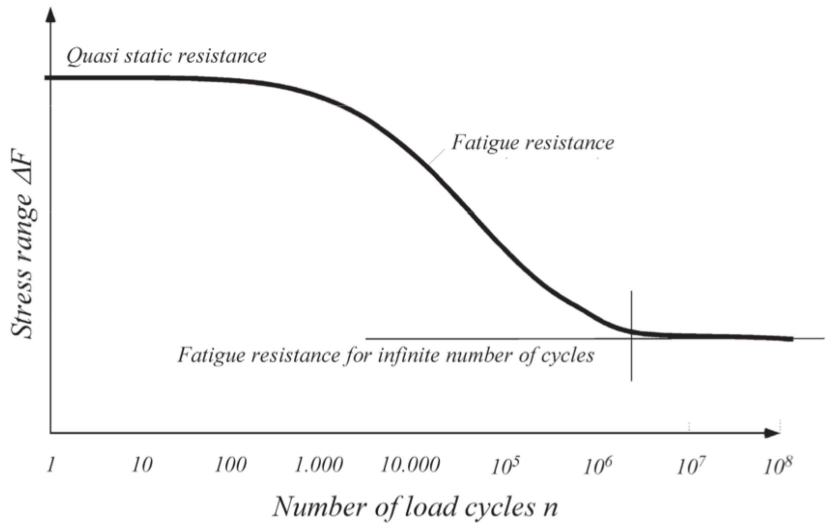

Figure 2: Stress vs no of cycles diagram for fatigue resistance

Is it important to note that the failure mode could be different for the static loading and fatigue cyclic loading as the resistance associated with different failure modes varies with the number of cycles. This technical note relies on the resistant values reported in pre-qualification document prepared in accordance with EAD 330250.

EAD 330250 has three assessment methods for the pre-qualification of fasteners under fatigue cyclic loading depending on the intended use, namely Method A (interactive method), Method B (simple method) and Method C (linearized method). The assessment method is stated in the pre-qualification report (such as ETA) and design method might be different based on the assessment method. The design method in this technical note is aligned to "*simplified method*" (also called Method II in EOTA TR 061). This design method is applicable to fastener pre-qualified using all three assessment methods from EAD 330250. If the fastener is pre-qualified in accordance with method A and C, a more detailed design method, called "*complete method*" (or Method I in EOTA TR 061) could be used. Please refer to Table 1 below. The Goodman diagram could be used if the fastener is subjected to a combination of fatigue cyclic and static load. Further details on this method could be found in EOTA TR 061.

Table 1: Fatigue design method based on assessment method

Assessment Method in EAD 330250	Design Method in EOTA TR 061
A	I or II
B	II
C	I or II

In this Technical Note, the fastener's fatigue resistance is calculated for $2x10^6$ load cycles. In general, the fatigue resistance is constant after $2x10^6$ cycles and thus, the resistance calculated from this technical note is also same for the infinite load cycles.

5. Derivation of forces acting on fasteners

Section 4 of AS 5216 applies.

6. Verification of fastener Strength

6.1. General

The ultimate strength of the fastener shall be verified in accordance with Equation 3.2.1 in AS 5216 considering modes of failure under tensile loading (Clause 6.2), modes of failure under shear loading (Clause 6.3) and combined tensile and shear loading (Clause 6.4).

The mode of failure calculated to provide the lowest design strength shall be adopted for ultimate limit state design.

6.2. Tensile strength of fasteners

The design of fasteners subjected to tensile loading shall be performed in accordance with the verifications listed in Table 2. The modes of failure producing the lowest design strength shall be adopted.

Table 2: Verifications required for fasteners loaded in tension

Failure Mode	Ref Clause	Single fastener	Fastener Group	
			Most loaded fastener	Fastener Group
Steel failure	7.2	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{*} \leq \phi_{Ms,N,fat} . \Delta N_{Rk,s}$	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{h*} \leq \phi_{Ms,N,fat} . \psi_{F,N} . \Delta N_{Rk,s}$	
Concrete cone failure	7.3	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{*} \leq \phi_{Mc,fat} . \Delta N_{Rk,c}$		$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{g*} \leq \phi_{Mc,fat} . \Delta N_{Rk,c}$
Pull-out failure[1]	7.4	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{*} \leq \phi_{Mp,fat} . \Delta N_{Rk,p}$	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{h*} \leq \phi_{Mp,fat} . \psi_{F,N} . \Delta N_{Rk,p}$	
Concrete splitting failure	7.5	$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{*} \leq \phi_{Mc,fat} . \Delta N_{Rk,sp}$		$\frac{1}{\phi_{F,fat}} . \Delta N_{fk}^{g*} \leq \phi_{Mc,fat} . \Delta N_{Rk,sp}$

Concrete blow-out failure	7.6	$\frac{1}{\phi_{F,fat}} . \Delta N^{*}_{fk} \leq \phi_{Mc,fat} . \Delta N_{Rk,cb}$		$\frac{1}{\phi_{F,fat}} . \Delta N^{g*}_{fk} \leq \phi_{Mc,fat} . \Delta N_{Rk,cb}$
[1] Applicable to post-installed mechanical fasteners, bonded expansion fasteners and headed fasteners. $\phi_{F,fat}$ is determined from the pre-qualification report. It is recommended to use 1.0 if further information is not available. If the detailed information is not available, the following values of the capacity reduction factors can be used. $\phi_{Ms,N,fat} = \frac{1}{1.35}$ $\phi_{Mc,fat} = \frac{1}{1.5}$ $\phi_{Mp,fat} = \frac{1}{1.5}$				

6.3. Shear strength of fasteners

The design of fasteners subjected to shear loading shall be performed in accordance with the verifications listed in Table 3. The modes of failure producing the lowest design strength shall be adopted.

Table 3: Verifications required for fasteners loaded in shear

Failure Mode	Ref Clause	Single fastener	Fastener Group	
			Most loaded fastener	Fastener Group
Steel failure without lever arm	8.2	$\frac{1}{\phi_{F,fat}} . \Delta V^{*}_{fk} \leq \phi_{Ms,V,fat} . \Delta V_{Rk,s}$	$\frac{1}{\phi_{F,fat}} . \Delta V^{h*}_{fk} \leq \phi_{Ms,V,fat} . \psi_{F,V} . \Delta V_{Rk,s}$	
Concrete pry-out failure	8.3	$\frac{1}{\phi_{F,fat}} . \Delta V^{*}_{fk} \leq \phi_{Mc,fat} . \Delta V_{Rk,cp}$		$\frac{1}{\phi_{F,fat}} . \Delta V^{g*}_{fk} \leq \phi_{Mc,fat} . \Delta V_{Rk,cp}$
Concrete edge failure	8.4	$\frac{1}{\phi_{F,fat}} . \Delta V^{*}_{fk} \leq \phi_{Mc,fat} . \Delta V_{Rk,c}$		$\frac{1}{\phi_{F,fat}} . \Delta V^{g*}_{fk} \leq \phi_{Mc,fat} . \Delta V_{Rk,c}$
If the detailed information is not available, the following values of the capacity reduction factors can be used. $\phi_{Ms,V,fat} = \phi_{Ms,N,fat} = \frac{1}{1.35}$ $\phi_{Mc,fat} = \frac{1}{1.5}$				

6.4. Combined tension and shear strength of fastener

Verification of strength of fasteners under combined tension and shear loading shall be in accordance with Clause 9.

7. Design for tensile fatigue loading

7.1. General

The verifications in Table 2 shall be undertaken in accordance with Clause 7.2 to 7.6.

> ***Note:***
> *The complete method from TR 061 can also be used to calculate the characteristic tensile capacities of the fasteners if all the required information is available in the product pre-qualification report.*

7.2. Steel failure

The tensile fatigue resistance of the fastener to steel failure ($\Delta N_{Rk,s}$) shall be calculated from the product prequalification report.

7.3. Concrete cone failure

The tensile fatigue resistance of a fastener or a group of fasteners to concrete cone failure for 2x10[6] load cycles ($\Delta N_{Rk,c}$) shall be calculated as follows:

$$\Delta N_{Rk,c} = \eta_{k,c,N,fat,\infty} \, . \, N_{Rk,c}$$

Where,

$\Delta N_{Rk,c}$	=	fatigue resistance of a fastener or a group of fasteners loaded in tension to concrete cone failure for 2x10[6] load cycles
$N_{Rk,c}$	=	Characteristic strength of a fastener or a group of fasteners to concrete cone failure for static loading and shall be calculated from AS 5216 Section 6
$\eta_{k,c,N,fat,\infty}$	=	Reduction factor for concrete cone failure and determined from product prequalification report
	=	0.5 if further information is not available

7.4. Pull-out failure

For the fatigue resistance against pull-out failure ($\Delta N_{Rk,p}$) under tensile fatigue loading is product dependent. It shall be obtained from product prequalification report.

7.5. Concrete splitting failure

The tensile fatigue resistance of a fastener or a group of fasteners to concrete splitting failure for 2x10[6] load cycles ($\Delta N_{Rk,sp}$) shall be calculated as follows:

$$\Delta N_{Rk,sp} = \eta_{k,sp,N,fat,\infty} N_{Rk,sp}$$

Where,

$\Delta N_{Rk,sp}$	=	fatigue resistance of a fastener or a group of fasteners loaded in tension to concrete splitting failure for 2x10[6] load cycles
$N_{Rk,sp}$	=	Characteristic strength of a fastener or a group of fasteners to concrete splitting failure for static loading and shall be calculated from AS 5216 Section 6
$\eta_{k,sp,N,fat,\infty}$	=	Reduction factor for splitting failure and determined from product prequalification report
	=	0.5 if further information is not available

7.6. Concrete blow-out failure

The tensile fatigue resistance of a fastener or a group of fasteners to concrete blow-out failure for 2x10[6] load cycles ($\Delta N_{Rk,cb}$) shall be calculated as follows:

$$\Delta N_{Rk,cb} = \eta_{k,cb,N,fat,\infty} N_{Rk,cb}$$

Where,

$\Delta N_{Rk,cb}$	=	fatigue resistance of a fastener or a group of fasteners loaded in tension to concrete blow-out failure for 2x10[6] load cycles
$N_{Rk,cb}$	=	Characteristic strength of a fastener or a group of fasteners to concrete blow-out failure for static loading and shall be calculated from AS 5216 Section 6
$\eta_{k,cb,N,fat,\infty}$	=	Reduction factor for blow-out failure and determined from product prequalification report
	=	0.5 if further information is not available

8. Design for shear fatigue loading

8.1. General

The verifications in Table 3 shall be undertaken in accordance with Clause 8.2 to 8.4.

Note:
The complete method from TR 061 can also be used to calculate the characteristic shear capacities of the fasteners if all the required information is available in the product pre-qualification report.

8.2. Steel failure without lever arm

The presence of a lever arm for the purpose of design for shear loading shall be determined in accordance with AS 5216 Clause 4.2.2.3 and Clause 4.2.2.4.

The shear fatigue resistance of the fastener to steel failure without lever arm ($\Delta V_{Rk,s}$) shall be calculated from the product prequalification report.

8.3. Concrete pry-out failure

The shear fatigue resistance of a fastener or a group of fasteners to concrete pry-out failure for $2x10^6$ load cycles ($\Delta V_{Rk,cp}$) shall be calculated as follows:

$$\Delta V_{Rk,cp} = \eta_{k,cp,V,fat,\infty} V_{Rk,cp}$$

Where,

$\Delta V_{Rk,cp}$	=	fatigue resistance of a fastener or a group of fasteners loaded in shear to concrete pry-out failure for $2x10^6$ load cycles
$V_{Rk,cp}$	=	Characteristic strength of a fastener or a group of fasteners to concrete pry-out failure for static loading and shall be calculated from AS 5216 Section 7
$\eta_{k,cp,V,fat,\infty}$	=	Reduction factor for concrete pry-out failure and determined from product prequalification report
	=	0.5 if further information is not available

8.4. Concrete edge failure

The shear fatigue resistance of a fastener or a group of fasteners to concrete edge failure for $2x10^6$ load cycles ($\Delta V_{Rk,c}$) shall be calculated as follows:

$$\Delta V_{Rk,c} = \eta_{k,c,V,fat,\infty} V_{Rk,c}$$

Where,

$\Delta V_{Rk,c}$	=	fatigue resistance of a fastener or a group of fasteners loaded in shear to concrete edge failure for $2x10^6$ load cycles
$V_{Rk,c}$	=	Characteristic strength of a fastener or a group of fasteners to concrete edge failure for static loading and shall be calculated from AS 5216 Section 7

$\eta_{k,c,V,fat,\infty}$	=	Reduction factor for concrete edge failure and determined from product prequalification report
	=	0.5 if further information is not available

9. Design for combined tension and shear loading

Verification of strength of fasteners under combined and shear loading shall be in accordance with equation (1). The verification shall be conducted for steel failure and failure modes other than steel failure separately. The largest value of $\beta_{N,fat}$ and $\beta_{V,fat}$ for the different failure modes under consideration shall be taken.

$$(\beta_{N,fat})^{\alpha} + (\beta_{V,fat})^{\alpha} \leq 1 \quad (1)$$

With

$$\beta_{N,fat} = \frac{\Delta N_{Ek}}{\phi_{F,fat}\phi_{M,fat}\,\psi_{F,N}\,\Delta N_{Rk}} \leq 1 \quad (2)$$

$$\beta_{V,fat} = \frac{\Delta V_{Ek}}{\phi_{F,fat}\phi_{M,fat}\,\psi_{F,V}\,\Delta V_{Rk}} \leq 1 \quad (3)$$

Where,

$\psi_{F,N}$	=	reduction factor applied to the tension resistance to account for the unequal distribution of the tension load acting on the fixture to the individual fasteners of a group
	≤	1, given in product prequalification report
$\psi_{F,V}$	=	reduction factor applied to the shear resistance to account for the unequal distribution of the shear load acting on the fixture to the individual fasteners of a group
	≤	1, given in product prequalification report
	=	1, for groups with 2 fasteners under shear load perpendicular to the axis of the fasteners when the fixture is not restrained against in-plane rotation
α	=	α_s for verification of steel failure, determined from product prequalification
	=	α_c for verification failure modes other than steel failure, determined from product prequalification
ΔN_{Ek}	=	Peak to peak amplitude of the fatigue tensile action
ΔN_{Rk}	=	fatigue resistance for the considered failure mode
ΔV_{Ek}	=	Peak to peak amplitude of the fatigue shear action
ΔV_{Rk}	=	fatigue resistance for the considered failure mode

10. References

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

[2] EAD 330250, Post–installed fasteners in concrete under fatigue cyclic loading, EOTA, 2018

[3] CEN (European Committee for Standardization). (2018). EN 1992-4: Eurocode 2: Design of concrete structures - Part 4: Design of fastenings for use in concrete. Brussels: CEN

[4] TR-061, Design method for fasteners in concrete under fatigue cyclic loading, EOTA, 2020

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

[6] Wohler, A. Über die festigkeitsversuche mit eisen und stahl. Ernst & Korn., 1870

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