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# Factors influencing the seismic design and evaluation of post-installed steel anchors in concrete

*E. del Rey Castillo & J.M. Ingham*

University of Auckland, Auckland, New Zealand

## ABSTRACT

The recent Amendment to the New Zealand concrete structures standard 3101 requires post-installed anchors to be qualified and designed in accordance with the European standards ETAG 001, Annex E and EOTA TR045 respectively, moving away from the American standards defined in ACI 355 and ACI 318. This amendment was introduced because the European standards are newer and the seismic requirements are more stringent and arguably more applicable to an actual seismic loading scenario. Despite these improvements, several concerns remain in place regarding the suitability of both the European and the American standards for the seismic conditions encountered in New Zealand.

A review of the qualification and design process as outlined in both the American and the European standards had been compiled, highlighting the differences in how seismic actions are addressed. The weaknesses and shortfalls of both standards from a New Zealand perspective are summarised, critical questions are introduced, and solutions are proposed. The objective of the study was to stimulate discussion amongst engineers to reach a consensus on how post-installed anchors should be designed and evaluated in a seismic environment. The eventual motivation is to decide on appropriate content for a future release of NZS 3101 Chapter 17.

## 1 INTRODUCTION

Post-installed steel anchors are typically used to transfer loads from structural and non-structural elements to the main concrete structure of a building by means of tension, shear, or a combination of tension and shear loading. Post-installed steel anchors are broadly classified into three categories depending on the load-transfer mechanism, 1) screw anchors, 2) expansion anchors, and 3) chemical anchors. Screw anchors are screwed into the concrete after drilling a hole that is the same size as the shaft of the anchor, thereby forcing

the thread to cut into the concrete. Expansion anchors feature a sleeve that expands by means of a conical-shaped head when torque is applied into the anchor, generating friction between the sleeve and the walls of the hole that was previously drilled into the concrete. Chemical anchors transfer the forces through a binder, which is typically a cementitious binder or an epoxy resin. Screw and expansion anchors are considered herein, while chemical anchors are out of the scope of the current discussion.

All failure modes that the anchor-concrete mechanism can possibly exhibit need to be considered when designing or evaluating post-installed anchors. Failure modes are divided depending on the type of load applied, being either tension or shear loading. The most common failure mechanisms related to tension loads are illustrated in Figure 1. It is important to note that pull-out and pull-through failure can only happen with expansion anchors, due to low friction between the sleeve and concrete or between the sleeve and shaft respectively. The most common failure mechanisms for shear load are illustrated in Figure 2. For special types of anchors, further non-standardised failure modes can be observed.

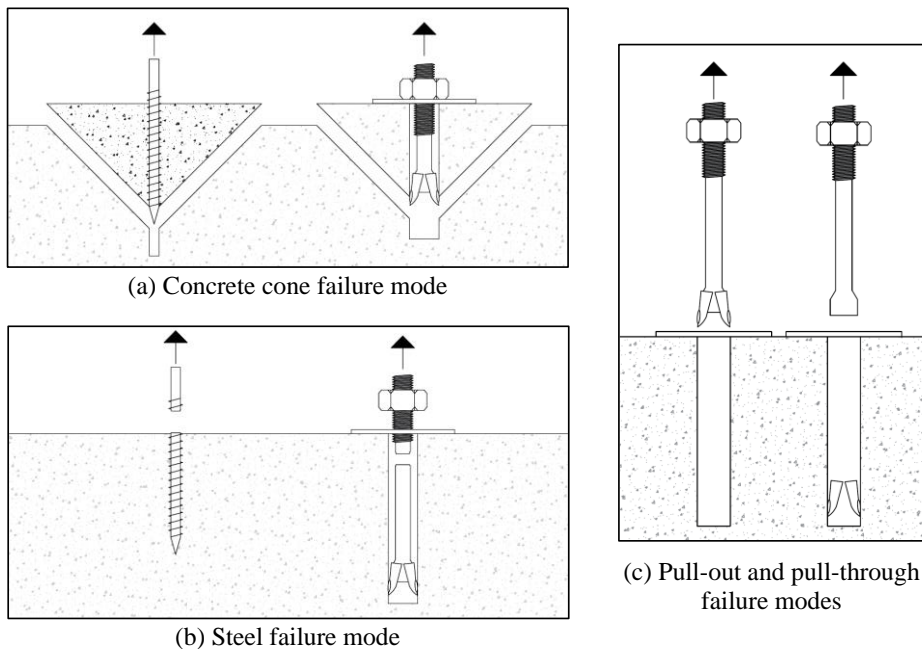


Figure 1: Failure modes related to tension loads

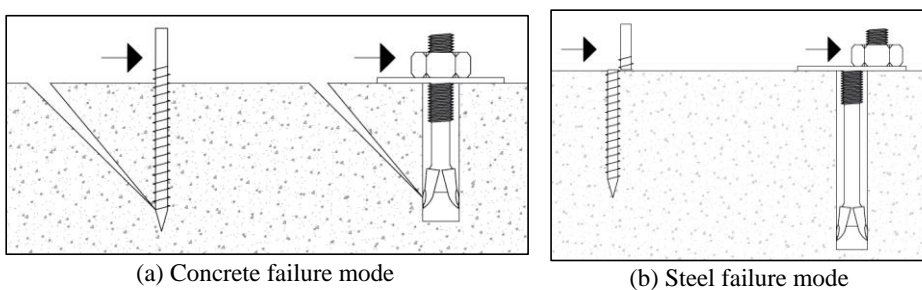


Figure 2: Failure modes related to shear loads

Chapter 17 of the New Zealand Concrete Structures standard NZS 3101 (2006) (hereafter referred to as the NZS 3101 standard for simplicity) details provisions for the design of post-installed anchors, although there is no provision for the evaluation of anchor strength. The first time that the design of post-installed anchors was addressed in the NZS 3101 standard was in the 2006 version, which was based on Appendix D of the 2002 version of the American Concrete Institute Building Code Requirements for Structural Concrete ACI 318 (2002) (referred to as the ACI 318 code for simplicity). An amendment to the 2002 version of the

ACI 318 code was introduced to account for anchors installed in uncracked concrete without splitting controlling reinforcement, with these amendments not subsequently copied into the NZS 3101 standard. This type of anchorage failure was observed in New Zealand after the Christchurch and Kaikōura earthquakes, and may have contributed to the failure of a precast panel that resulted in the loss of a woman's life (RadioNZ 2012). But in addition to that amendment, a new version of the ACI 318 code was published in 2008 and another one in 2014, while in New Zealand the provisions from the 2002 version of NZS 3101 were still being used until Amendment 3 was published in 2018. Chapter 17 of the NZS 3101 standard was outside the scope of Amendment 3 that was published as a result of findings from the Canterbury Earthquakes Royal Commission, such that extensive amendments to Chapter 17 were deemed to not be permitted. Instead, a decision was made to adopt Annex E of the Guideline for European Technical Approval of Metal Anchors for Use in Concrete ETAG 001 (2013) (referred to as the ETAG 001 guideline for simplicity) for assessing the behaviour of steel anchors, and to adopt the Technical Report 045 on Design of Metal Anchors For Use In Concrete Under Seismic Actions from the European Organisation for Technical Approvals (2013) (referred to as the TR045 report for simplicity) for the design of post-installed anchors. This decision was taken without undertaking a comprehensive critique of the standards (both American and European) and without trying to improve nor modify the standards, because of a paucity of New Zealand experimental research relevant to the topic. In addition, Annex E of the ETAG 001 guideline and the TR045 report only address seismic evaluation and seismic design, while non-seismic evaluation is addressed in the main body of the ETAG 001 guideline and non-seismic design is addressed in Annex C of the ETAG 001 guideline. **These other documents should also have been referenced in the NZS 3101 standard to clearly guide engineers in how to design and evaluate post-installed anchors.**

The most common use of post-installed anchors in New Zealand is for suspended installations (e.g. cable trays, water, HVAC and fire sprinklers), i.e. non-structural elements. Concrete substrates that may compromise the strength capacity of an anchor are common in the industry, given the popularity of tee beams and hollow core floors in the past and the current increased usage of composite steel-concrete slabs. But these types of concrete substrate are not within the scope of any design standard, and will probably need to be accounted for when the next Chapter 17 of the New Zealand Concrete Standard is prepared.

## 2 PERFORMANCE CRITERIA FOR DIFFERENT SCENARIOS

The performance criteria for an anchorage system needs to be defined by an engineer before the anchor itself is designed. Examples of these performance criteria might be whether or not the anchor is expected to resist seismic actions, or the likelihood of the concrete substrate to crack either during service or during an earthquake. Some examples of where the anchor can be expected to crack or to not crack are detailed in Table 1.

*Table 1: Performance criteria for concrete cracking*

Concrete is expected to crack	Concrete is expected to not crack
<ul style="list-style-type: none"> <li>• Shear walls, especially in the plastic hinge regions</li> <li>• Columns, especially in the plastic hinge regions</li> <li>• Beams, in the plastic hinge regions always and in the mid-span region when high gravity load is expected</li> <li>• Potentially, heavy elements that could injure</li> </ul>	<ul style="list-style-type: none"> <li>• Mass foundation pads</li> <li>• Non-structural panels</li> <li>• Reservoirs, dams, silos and deposits</li> <li>• Soffit of precast prestressed floors</li> <li>• Post-tensioned floors</li> <li>• Mid-span regions of beams when low gravity load is expected</li> <li>• Potentially minor, light elements that do not pose a life threatening risk</li> </ul>

### 3 DESIGN OF POST-INSTALLED ANCHORS

In this section both the 2014 version of the ACI 318 code (more specifically Chapter 17 of ACI 318 (2014) pertaining to anchorage in concrete) and the TR045 report are described in general terms, with emphasis on the seismic provisions. A number of factors are not considered, such as the use of lightweight concrete, the installation of anchors close to an edge, and the effect of inadequate installation.

#### 3.1 ACI 318 Building Code Requirements for Structural Concrete (2014)

The design philosophy of the ACI 318 code is based on the assumption that the behaviour of post-installed anchors in cracked concrete is the worst case scenario and it is assumed that “*the concrete is cracked unless it can be demonstrated that the concrete remains uncracked*” (Section 17.2.3.4.4). Further, the seismic design of post-installed anchors is not considered in ACI 318, and the design of post-installed anchors is undertaken assuming static loads but reducing the characteristic strength of the anchor to account for seismic loads when the characteristic strength of the anchor is evaluated using the standard ACI 355 (2007). The process to account for seismic loads is discussed further below in Section ACI 355-2 Qualification of Post-Installed Mechanical Anchors in Concrete (2007).

The design process according to ACI starts with determining the characteristic strength of the post-installed anchor, which can be assessed using the ACI 355 (2007) standard for Qualification of Post-Installed Mechanical Anchors in Concrete. This characteristic strength value is often provided by suppliers, with engineers typically not having the experimental information required in order to discern how the characteristic strength value was determined. Additionally, it has been observed that the values reported by suppliers are often not based on experimental data. Instead, suppliers often only undertake testing for some of their products rather than testing the entire product range, and then extrapolate or interpolate the available experimental data for the entire range of products. This practice may give incorrect results, given that anchors of the same type may exhibit various failure modes depending on the size and embedment depth, which results in varying strengths that cannot be correctly extrapolated or interpolated. However, engineers often do not know how the characteristic strength values were obtained.

A strength reduction factor  $\phi$  ranging from 0.45 to 0.75 is prescribed in the ACI 318 code Section 17.3.3 for isolated anchors, depending on the governing failure mode, the type of load applied, and the anchor Category, which is also determined using ACI 355. After the strength reduction factor is determined, the design process is divided into tension and shear, and then further subdivided into each expected failure mode.

##### 3.1.1 Design requirements for tensile loading (17.4 in ACI 318)

Several equations are used to calculate the nominal strength of a post-installed anchor for the different failure modes. Different parameters are considered in each equation, with the steel and anchor shaft properties being included in the equation that governs steel failure and the concrete properties being included in the equations that govern concrete failure, but modified by a number of  $\psi$  factors to account for edge effects, the effect of uncracked concrete, and the effect of the anchor being installed close to the edge of the concrete member. The anchor strength to resist pull-out failure must be established experimentally because of the complexity of standardising the vast range of available products.

##### 3.1.2 Design of anchors to resist shear loading (17.5 in ACI 318)

The design of anchors to resist shear loading is similar to the design of anchors to resist tensile loading, with various equations that govern each failure mode. A critical factor is that the  $\psi$  factor for anchors installed in a concrete member that is not expected to crack is 1.4, which infers that the anchor will resist a higher load when installed in uncracked concrete.

### 3.1.3 Interaction of tensile and shear forces (17.6 in ACI 318)

If the ratio of tensile/shear or shear/tensile loading is smaller than 0.2 then the smaller load can be disregarded, but if this loading ratio is higher than 0.2 then Equation 1 needs to be used to account for the combination of tension and shear load. This criteria and Equation 7 have been implemented into Chapter 17 of the NZS 3101 standard.

$$\left(\frac{N_{ua}}{\phi N_n}\right)^{5/3} + \left(\frac{V_{ua}}{\phi V_n}\right)^{5/3} = 1 \quad (1)$$

### 3.2 ETAG 001 European Guideline on Design Methods for Anchorages Annex C (2013) and EOTA TR045 Technical Report 045 (2013)

The design guideline for post-installed anchors in Europe is ETAG 001 Annex C. The methodology is analogous to that of the American code ACI 318 explained above, despite a couple of differences, such as the equation for tensile-shear force interaction. The main difference is that the European Organisation for Technical Approvals developed a Technical Report (EOTA TR 045) for the Design of Metal Anchors Under Seismic Conditions. The seismic reduction factor  $\alpha_{seis}$  is only applicable to out-of-the-ordinary anchors and anchor groups as can be inferred from Table 2, but the main change with respect to non-seismic conditions is the amount of testing necessary in the evaluation process, as further discussed below.

Table 2: Reduction factor  $\alpha_{seis}$  according to Table 5.4 from the TR 045 report

Loading	Failure mode	Single anchor <sup>1)</sup>	Anchor group
tension	Steel failure	1,0	1,0
	Pull-out failure	1,0	0,85
	Combined pull-out and concrete failure	1,0	0,85
	Concrete cone failure		
	• undercut anchors with the same behaviour as cast-in headed fasteners <sup>2)</sup>	1,00	0,85
	• all other anchors	0,85	0,75
	Splitting failure	1,0	0,85
shear	Steel failure	1,0	0,85
	Concrete edge failure	1,0	0,85
	Concrete pry-out failure		
	• undercut anchors with the same behaviour as cast-in headed fasteners <sup>2)</sup>	1,0	0,85
	• all other anchors	0,85	0,75

<sup>1)</sup> In case of tension loading single anchor also addresses situations where only 1 anchor in a group of anchors is subjected to tension.

<sup>2)</sup> Undercut anchors with the same concrete cone capacity in cracked concrete as cast-in headed fasteners, i.e. at least  $N_{Rk,e} = 8.0 \cdot (f_{ck,cube})^{0.5} \cdot (h_{ef})^{1.5}$ ; given in the relevant ETA.

## 4 EVALUATION OF POST-INSTALLED ANCHORS

The evaluation of the anchor characteristic strength is necessary before the design of the anchors can be undertaken. In the USA and in Europe this process is usually performed by approved laboratories, being either International Code Council Evaluation Service (ICC-ES) or International Organization for Standardization (ISO) laboratories. In New Zealand these approval methods do not exist and engineers usually rely on internationally approved products or on products tested locally by well-known independent institutions such as BRANZ or a university. While the majority of the tests described in both ACI 355-2 and ETAG 001 are similar, the differences in the seismic tests are significant. Therefore these seismic tests are described below in more detail.

#### 4.1 ACI 355-2 Qualification of Post-Installed Mechanical Anchors in Concrete (2007)

The tests prescribed in ACI 355-2 are force-based, which means that the final result is the tensile and shear characteristic strength of the anchor with little attention being given to the displacement or the ductility capacity of the anchor. The tests are divided into three broad categories, 1) reference tests consisting exclusively of tension tests, 2) reliability tests to ensure appropriate anchor behaviour despite reduced installation quality, and 3) service condition tests, where the seismic loading tests are included. The testing of the anchor tensile strength is more comprehensive than testing of the shear strength. Only one reference test is required to assess the shear strength as opposed to the four reference tests that are required to assess the tensile strength of the anchor. The differences in requirements between the tensile loading and the shear loading testing, together with the fact that the seismic tests are optional, suggests that this standard was not written with seismic loads being a high priority, as is the case in New Zealand. **Therefore any future Chapter 17 in the NZS 3101 standard detailing post-installed anchors should evaluate the shear strength of the anchor with the same degree of detail as for the tensile strength, i.e. low and high strength concrete in both cracked and uncracked conditions.**

The seismic tests described in the ACI 355-2 standard are relatively simple. The main requirement is that the anchors complete 140 cycles, being 10 cycles at half the monotonic load ( $N_{eq}$ ), 30 cycles at 75% of  $N_{eq}$  ( $N_i$ ), and 100 cycles at 50% of  $N_{eq}$  ( $N_m$ ), as described in Figure 3a. The residual strength of the anchor after the cycles have been completed must be at least 1.6 times half the monotonic load ( $N_{eq}$ ). No reasoning could be found for this particular loading protocol and the justification for the applicability to real earthquake loading. The shear protocol is similar to the tensile protocol, with 140 cycles to be completed and a residual load required to be 1.6 times the initial load. The main problem with the shear loading protocol is that the testing is only required in low-strength, cracked concrete. The load obtained with this protocol is not reliable when the anchor can exhibit different failure modes depending on the anchor and concrete properties. If the failure mode obtained when testing the anchor in low-strength cracked concrete is not steel failure then the failure mode can change to steel failure when high strength and/or uncracked concrete is used, and therefore the anchors may not complete the cycles. **Therefore any future Chapter 17 in the NZS 3101 standard detailing post-installed anchors must include seismic testing in all concrete conditions, being both low-strength and high-strength concrete that is both cracked and uncracked, and that accounts for all failure modes.**

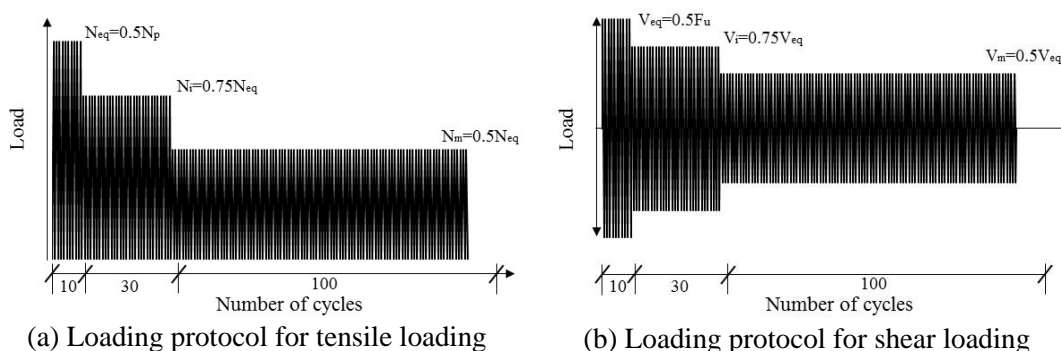


Figure 3: Loading protocols for simulated seismic tests according to ACI 355

#### 4.2 ETAG 001 European Guideline on Design Methods for Anchorages (2013)

The European evaluation document is more complex than the American counterpart and is divided into several parts. Part 1 describes the general testing for accordance with European Technical Approvals (ETA), which are relatively similar to those from the American standard. Parts 2 to 5 are dedicated to special types

of anchors and the Annexes provide extra information. For example, Annex A gives detailed information of testing set-ups and instrumentation.

#### 4.2.1 General characterization

Most of the tests for the general characterization described in Part 1 of ETAG 001 are relatively similar to those described in ACI 355. **An interesting addition is the testing for combined tension and shear loading, which could be incorporated into the future NZS 3101.**

#### 4.2.2 Seismic evaluation

The main advantage of ETAG 001 over ACI 355 in the New Zealand context is that ETAG 001 has an Annex E focused on the Assessment of Metal Anchors Under Seismic Actions. The tests that are required for each anchor depend on the seismicity of the region within Europe and the importance class of the building, as can be seen in Table 3. The design ground acceleration  $a_g$  is dependent on the seismic zone (e.g. Greece will have a higher ground acceleration than Germany), the soil factor is dependent on the type of ground where the structure is built (e.g. rocky soils have an S factor of 1 while a soil consisting of surface alluvium has an S factor of 1.4) and the Importance Class is analogous to the Importance Level in New Zealand. Two categories are described in ETAG 001 for the assessment of anchors in seismic regions to be used for non-structural elements, being Category C1 for areas where the  $a_g \cdot S$  value is between 0.05g and 0.1g and Category C2 for areas where the  $a_g \cdot S$  value is higher than 0.1g. Buildings with an Importance Class of 1 require only C1 regardless of the seismicity at the site. Anchors to be used for structural elements always require Category C2, and probably this conservative measure is justified as a life safety precaution.

*Table 3: Minimum recommended performance categories for anchors under seismic actions according to ETAG 001 Annex E Table 1.1*

Seismicity		Importance Class acc. to EN 1998-1:2004, 4.2.5			
	$a_g \cdot S^2)$	I	II	III	IV
Very low <sup>1)</sup>	$a_g \cdot S \leq 0,05 g$	ETAG 001 Part 1 to Part 5			
Low <sup>1)</sup>	$0,05 g < a_g \cdot S \leq 0,1 g$	C1	C1 <sup>3)</sup> or C2 <sup>4)</sup>		C2
	$a_g \cdot S > 0,1 g$	C1	C2		

<sup>1)</sup> Definition according to EN 1998-1:2004, 3.2.1.

<sup>2)</sup>  $a_g = \gamma_1 \cdot a_{gR}$  Design ground acceleration on type A ground (Ground types as defined in EN 1998-1:2004, Table 3.1);

$\gamma_1$  = importance factor (see EN 1998-1:2004, 4.2.5);

$a_{gR}$  = reference peak ground acceleration on type A ground (see EN 1998-1:2004, 3.2.1);

S = Soil factor (see e.g. EN 1998-1:2004, 3.2.2).

<sup>3)</sup> C1 for fixing non-structural elements to structures

<sup>4)</sup> C2 for fixing structural elements to structures

**The seismicity in ETAG 001 is not computed in the same manner as in New Zealand because it is in the Eurocode, so two options are available.** The first option is to use the ground acceleration map from GNS reported in Figure 4a, and use C1 for regions with a 475 year PGA of 0.1g or less and to use C2 for those regions where the PGA is higher than 0.1g. The second option would be to use the hazard factor Z map from the New Zealand Standard on Structural Design Actions NZS 1170.5 (2004) reported in Figure 4b and 4c. Similarly, C1 could be used when Z is equal to 0.13 and C2 could be used when Z is higher than 0.13. It is important to note that in both cases anchors designed to fix non-structural elements in Auckland would only require C1. The option of using C1 for Importance Level 1 can also be incorporated.

However, neither of the approaches described above appear to recognise that anchor demand depends on building characteristics, such as structural system, floor level or damping. Section 8 of the New Zealand Standard 1170-5 was developed to account for these aspects when calculating the design actions to apply on parts and components, but could also be used to calculate the percentage of  $g$  to be applied on the anchor and decide whether Category C2 is necessary or C1 is enough.

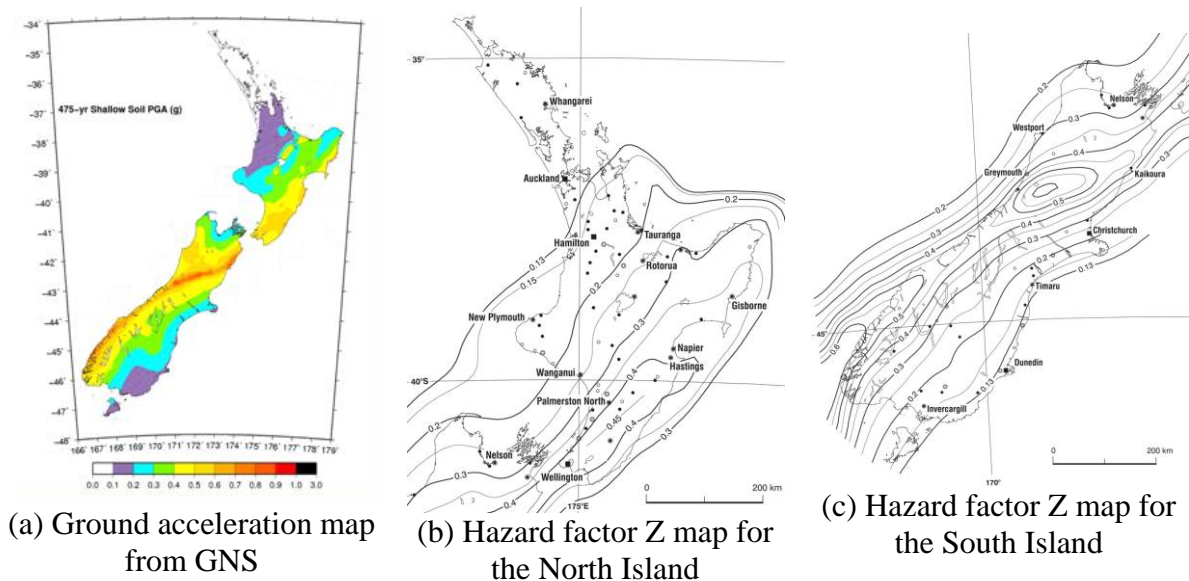


Figure 4: Seismicity maps for New Zealand

The tests pertaining to Category C1 are exactly the same as the seismic tests in ACI 355 so these tests will not be discussed again. The tests described in Category C2 and reported in Table 4 are more stringent than those described in Category C1. An improvement when compared to C1 is that the shear reference test has to be performed both in uncracked and in cracked conditions. However these tests are only to be conducted on anchors installed in low-strength concrete, but both low- and high-strength concrete are to be considered when the tensile strength is being evaluated. The loading protocols for seismic actions are different to those from Category C1 or ACI 355. A representation of the loading protocols is reported in Figure 5a for tensile assessment and in Figure 5b for shear assessment. As can be observed in these figures and in Table 4, not only the load but also the crack width is increased when compared to Category C1. The load is increased as a ratio between the load ( $N$  or  $V$ ) and the maximum load ( $N_{max}$  or  $V_{max}$ ). The maximum load is defined as 75% and 85% of the monotonic load for tensile and seismic strength assessment respectively. Similarly to the loading protocols from Category C1 and ACI 355, no reasoning could be found regarding the suitability of these loading protocols or how representative the protocols may be to real seismic loading conditions. **Any future standard will need to justify the existing loading protocols, or develop a new loading protocol if the existing protocols are not justifiable.** An additional test in Category C2 (test C2.5) requires the anchor to sustain a constant tensile load while the crack is subjected to opening and closing cycles.

Table 4: Additional tests for qualification of anchors under category C2 according to ETAG 001 Annex E Table 2.4

Test no.	Purpose of test	Concrete	Crack width $\Delta w$ <sup>1)</sup> [mm]	Minimum number of tests <sup>2)</sup>	Test procedure see Section	Assessment criteria see Section
C2.1a	Reference tension tests in low strength concrete	C20/25	0,8	5	2.4.2	3.2.1, 3.2.2
C2.1b	Tension tests in high strength concrete	C50/60	0,8	5	2.4.2	3.2.1, 3.2.2
C2.2 <sup>3)</sup>	Reference shear tests	C20/25	0,8	5	2.4.2	3.2.1, 3.2.3
C2.3	Functioning under pulsating tension load	C20/25	0,5 ( $\leq 0,5 \cdot N/N_{max}$ ) <sup>4)</sup> 0,8 ( $> 0,5 \cdot N/N_{max}$ )	5	2.4.3	3.2.1, 3.2.4
C2.4	Functioning under alternating shear load	C20/25	0,8	5	2.4.4	3.2.1, 3.2.5
C2.5	Functioning with tension load under varying crack width	C20/25	$\Delta w_1 = 0,0$ <sup>5)</sup> $\Delta w_2 = 0,8$	5	2.4.5	3.2.1, 3.2.6

- 1) Crack width  $\Delta w$  added to the width of hairline crack after anchor installation but before loading of anchor.  
 2) Test all anchor diameters for which the anchor is to be qualified for use in seismic applications. For anchors with different steel types, steel grades, production methods, head configurations (mechanical anchors), types of inserts (bonded anchors), multiple embedment depths and drilling methods see 2.2.  
 3) See 2.4.2  
 4) The tests may also be conducted in  $\Delta w = 0,8$  mm at all load levels ( $N/N_{max}$ ).  
 5)  $\Delta w_1 = 0,0$  mm is defined in 2.4.5.

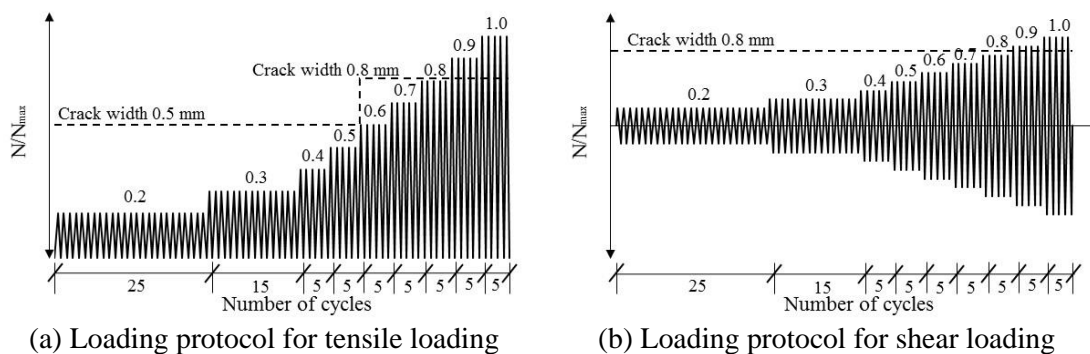


Figure 5: Loading protocols for simulated seismic tests for (a) tension and (b) shear loadings according to Category C2 of ETAG 001

## 5 RECOMMENDATIONS FOR THE CURRENT STATE OF DESIGN

Amendment 3 of the NZS 3101 standards prescribed ETAG 001 Annex E for anchor evaluation and the EOTA TR045 report for anchor design, although Annex E is only for seismic evaluation and the TR045 report is only for seismic design. **It can be interpreted that ETAG 001 Part 1 is to be used for non-seismic anchor evaluation and that ETAG 001 Annex C is to be used for non-seismic design.** The NZS 3101 standard does not clearly define when category C1 and C2 have to be used when designing non-structural elements. As explained in detail in the Seismic evaluation section above, two options are available to the engineer, to use either 1) the ground acceleration map from GNS or 2) the hazard factor map from the 1170.5 standard. In both cases Auckland, Northland and parts of Otago would be the only regions of New Zealand that would require only category C1 for non-structural elements. A more conservative solution

would be to specify C2 for the whole country, for both structural and non-structural elements. Alternatively, the engineering profession could choose to make the distinction between C1 and C2 based on when the structural elements or regions are expected to crack or to not crack, as described in Table 1, although this option is not currently contemplated in any guideline or standard. A final alternative could be to adopt Section 8 of the NZS 1170-5 standard to decide which testing Category is needed and to calculate the actions on the anchors. It is important to keep in mind that the seismic shear strength of anchors installed in uncracked concrete might be lower than when the same anchors are installed in cracked concrete.

## **6 AREAS IN NEED OF FURTHER RESEARCH AND POTENTIAL CHANGES IN A FUTURE CHAPTER 17 OF THE NZS 3101 STANDARD**

The seismic loading protocols of both the ACI 355 code and the ETAG 001 guideline need to be investigated to verify that these protocols accurately represent a real earthquake loading scenario and, if not, then whether new loading protocols should be developed.

The shear strength of anchors needs to be further investigated and the evaluation of the shear strength needs to be incorporated into a future Chapter 17 of the NZS 3101 standard. The influence of cracked vs uncracked concrete on the seismic shear strength needs to be verified. If the shear strength of anchors installed in uncracked concrete is lower than that of the same anchors installed in cracked concrete, then the seismic shear strength of the anchors installed in uncracked concrete needs to be evaluated, together with the strength of the anchors installed in cracked concrete.

The effect of inadequate confinement of the anchors as a result of using various types of substrates needs to be investigated, and potentially implemented into the Chapter 17 of the NZS 3101 standard as strength reduction factors when the anchor is not properly confined.

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