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Safe anchorage by the system of Qualification, Approval, and Design

Safe anchorage by the system of Qualification, Approval, and Design

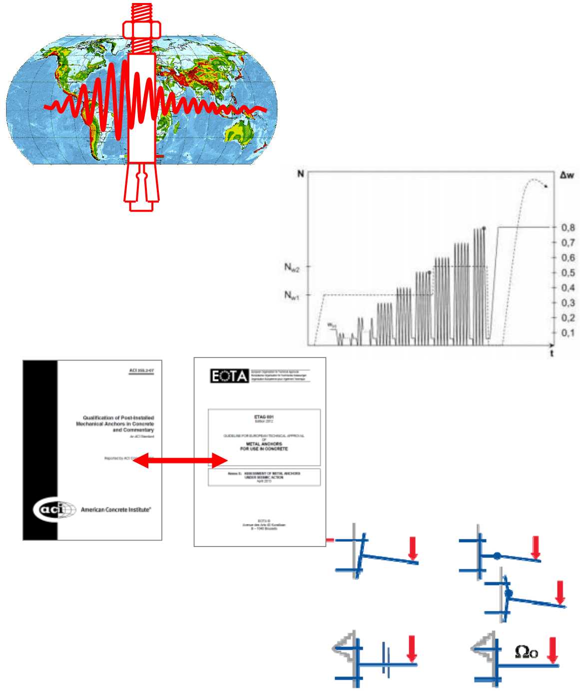
Safe anchorage by the system of Qualification, Approval, and Design

Seismic Approval Category C1/C2

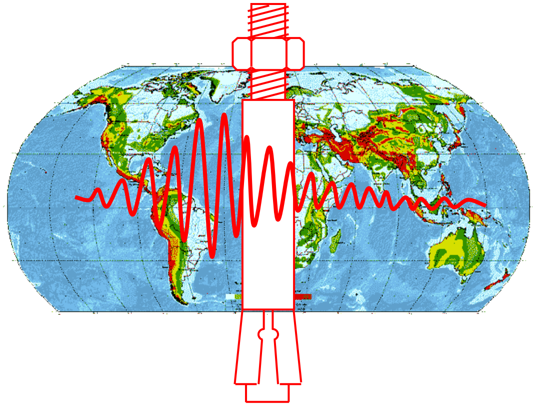
What‘s that?

The new European seismic design and qualification requirements for anchors

- Background and brief history of seismic anchorage
- Development of the new European seismic C2 qualification
- Comparison ACI 355 and ETAG C1/C2 seismic qualification
- Notes on seismic anchor design



Background and brief history of seismic anchorage

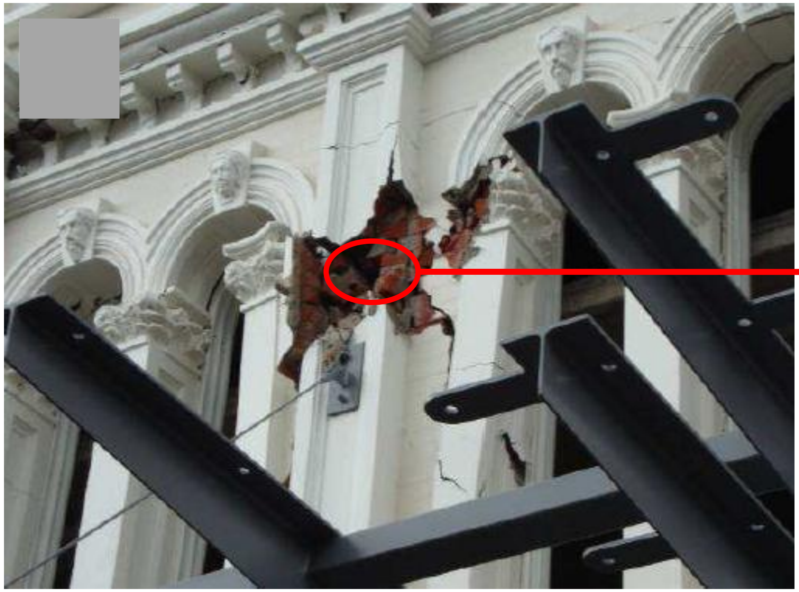


Taken from FEMA E-74

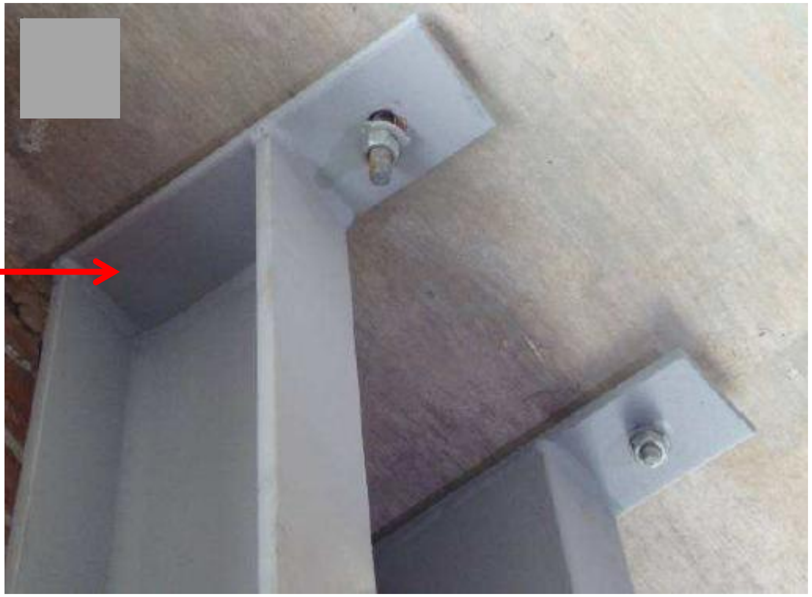
Background and brief history of seismic anchor approval

Example of structural EQ damage caused by failure of anchorage

2011 Christchurch Earthquake



Nearly collapsed façade due to insufficient anchorage of internal retrofit steel frame

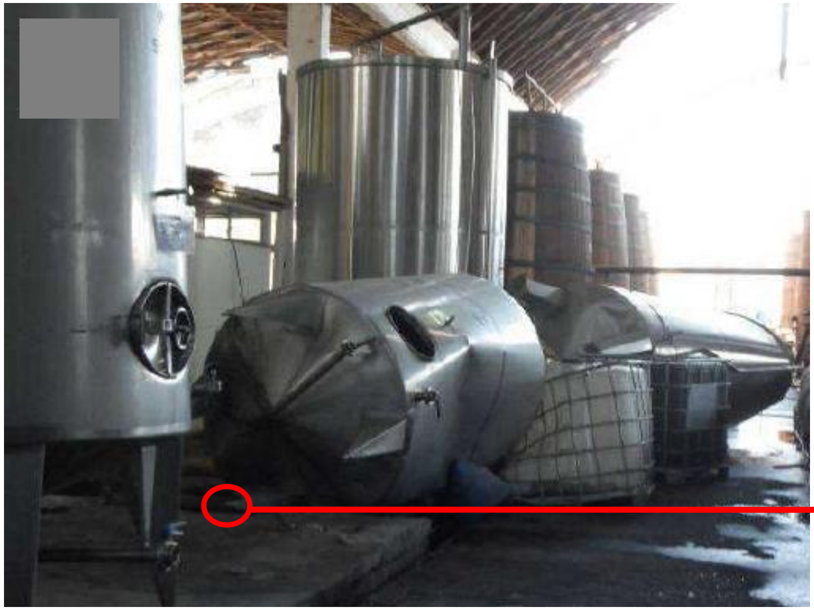


Detail of the displaced anchors at overhead footing of the retrofit steel frame

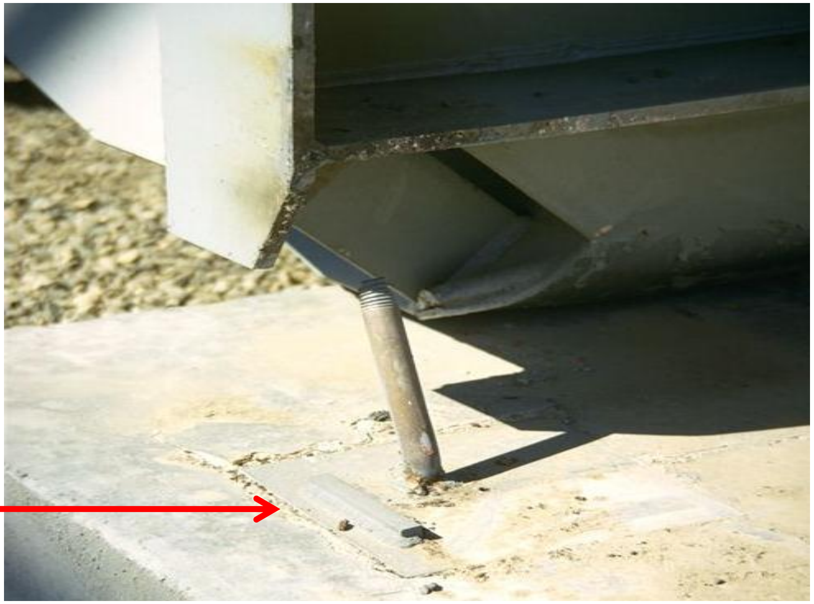
Background and brief history of seismic anchor approval

Example of nonstructural EQ damage caused by failure of anchorage

2010 Chile Earthquake



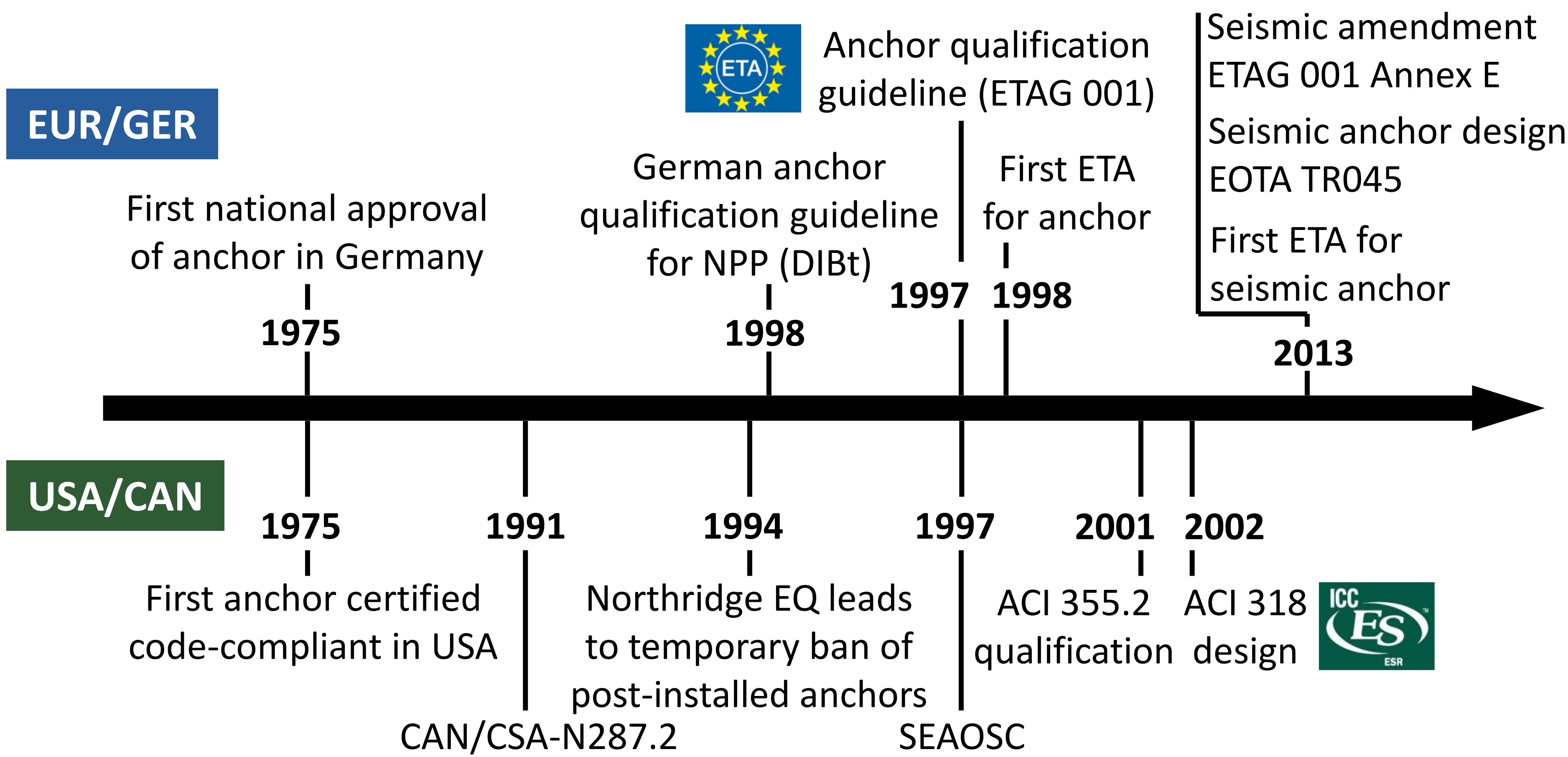
Silo for liquid storage toppled, tearing down further silos



Detail of the failed anchor, rupture at the threaded section of the bolt

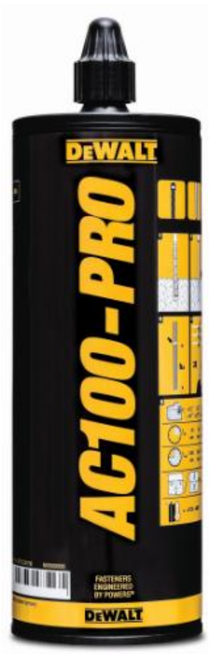
Background and brief history of seismic anchor approval

Timeline of code development for anchors used in seismic applications



Background and brief history of seismic anchor approval

First European seismic approvals (ETA)



Deutsches Institut für Bautechnik
Zulassungsstelle für Bauprodukte und Bauarten
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Authorised and notified according to Article 10 of the Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products (89/106/EEC)

Deutsches Institut für Bautechnik DIBt

Mitglied der EOTA
Member of EOTA

European Technical Approval ETA-13/0258

English translation prepared by DIBt - Original version in German language

Handelsbezeichnung *Trade name*	DeWalt AC100-PRO Verbundmörtel mit Ankerstange *DeWalt AC100-PRO injection resin with anchor rod*
Zulassungsinhaber *Holder of approval*	DeWalt Black & Decker Straße 40 65510 Idstein DEUTSCHLAND
Zulassungsgegenstand und Verwendungszweck *Generic type and use of construction product*	Verbunddübel zur Verankerung im Beton unter statischer, quasi-statischer oder seismischer Einwirkung (Leistungskategorie C1) *Bonded anchor for use in concrete under static, quasi-static or seismic action (performance category C1)*
Geltungsdauer: *Validity:* vom *from*	24 April 2013
bis *to*	15 March 2018
Herstellwerk *Manufacturing plant*	Herstellwerk 1 Herstellwerk 2
Diese Zulassung umfasst *This Approval contains*	45 Seiten einschließlich 36 Anhänge *45 pages including 36 annexes*

Electronic copy of the ETA by DIBt: ETA-13/0258

EOTA Europäische Organisation für Technische Zulassungen
European Organisation for Technical Approvals

Z25594.13 8.06.01-458/12

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Fax : (33) 01 60 05 70 37

Autorisé et notifié conformément à l'article 10 de la directive 89/106/EEC du Conseil, du 21 décembre 1988, relative au rapprochement des dispositions législatives, réglementaires et administratives des Etats membres concernant les produits de construction.

CSTB le futur en construction
MEMBRE DE L'EOTA

European Technical Approval ETA-13/0036

(English language translation, the original version is in French language)

Nom commercial : **Trade name:**	**DeWalt PTB-PRO**
Titulaire : **Holder of approval:**	**DeWalt Stanley Black&Decker Deutschland GmbH European Anchor Development Center Black-&-Decker Str. 40 65510 Idstein Germany**
Type générique et utilisation prévue du produit de construction : **Generic type and use of construction product:**	Cheville métallique, à expansion par vissage à couple contrôlé, de fixation dans le béton fissuré : diamètres M8, M10, M12, M16 et M20. **Torque-controlled expansion anchor for use in cracked concrete: sizes M8, M10, M12, M16, M20.**
Validité du : au : **Validity from / to:**	**03/06/2013 03/06/2018**
Usine de fabrication : **Manufacturing plant:**	**Plant 1 & 2**
Le présent Agrément technique européen contient : **This European Technical Approval contains:**	16 pages incluant 8 annexes faisant partie intégrante du document. **16 pages including 8 annexes which form an integral part of the document.**

Technique Européen annule et remplace ETA-13/0036 valide du 07/05/2013 au 07/05/2018
This European Technical Approval cancels and replaces ETA-13/0036 with validity from 07/05/2013 to 07/05/2018.

EOTA Organisation pour l'Agrément Technique Européen
European Organisation for Technical Approvals

For adhesive anchors:
Powers/Dewalt AC100-Pro

For mechanical anchors:
Powers/Dewalt PTB-Pro

Background and brief history of seismic anchor approval

Effect of seismic qualification on design data in the approval document

Example for an adhesive anchor

ESR-2582 | *Most Widely Accepted and Trusted* **Page 9 of 17**

TABLE 4—STEEL DESIGN INFORMATION FOR FRACTIONAL THREADED ROD

DESIGN INFORMATION		SYMBOL	UNITS	NOMINAL ROD DIAMETER (inch)[1]						
				3/8	1/2	5/8	3/4	7/8	1	1 1/4
Threaded rod nominal outside diameter		d	inch (mm)	0.375 (9.5)	0.500 (12.7)	0.625 (15.9)	0.750 (19.1)	0.875 (22.2)	1.000 (25.4)	1.250 (31.8)
Threaded rod effective cross-sectional area		A_{se}	inch² (mm²)	0.0775 (50)	0.1419 (92)	0.2260 (146)	0.3345 (216)	0.4617 (298)	0.6057 (391)	0.9691 (625)
ASTM A36 and F1554, Grade 36	Nominal strength as governed by steel strength (for a single anchor)	N_{sa}	lbf (kN)	4,495 (20.0)	8,230 (36.6)	13,110 (58.3)	19,400 (86.3)	26,780 (119.1)	35,130 (156.3)	56,210 (250.0)
		V_{sa}	lbf (kN)	2,695 (12.0)	4,940 (22.0)	7,860 (35.0)	11,640 (51.8)	16,070 (71.4)	21,080 (93.8)	33,725 (150.0)
	Reduction factor for seismic shear	$\alpha_{V,seis}$	-	Not applicable	0.85	0.85	0.85	0.85	0.80	0.80
	Strength reduction factor for tension[2]	ϕ	-	0.75						
	Strength reduction factor for shear[2]	ϕ	-	0.65						

TABLE 7—BOND STRENGTH DESIGN INFORMATION FOR FRACTIONAL THREADED RODS AND REINFORCING BARS IN HOLES DRILLED WITH A HAMMER DRILL AND CARBIDE BIT[1]

DESIGN INFORMATION		SYMBOL	UNITS	NOMINAL ROD DIAMETER (inch) / REINFORCING BAR SIZE							
				3/8 or #3	1/2 or #4	5/8 or #5	3/4 or #6	7/8 or #7	1 or #8	#9	1 1/4 or #10
Minimum embedment		$h_{ef,min}$	inch (mm)	2 3/8 (60)	2 3/4 (70)	3 1/8 (79)	3 1/2 (89)	3 1/2 (89)	4 (102)	4 1/2 (114)	5 (127)
Maximum embedment		$h_{ef,max}$	inch (mm)	4 1/2 (114)	6 (152)	7 1/2 (191)	9 (229)	10 1/2 (267)	12 (305)	13 1/2 (343)	15 (381)
Temperature Range A[2,4,5]	Characteristic bond strength in cracked concrete[7]	$\tau_{k,cr}$	psi (N/mm²)	Not applicable	871 (6.0)	907 (6.3)	907 (6.3)	907 (6.3)	918 (6.3)	918 (6.3)	918 (6.3)
	Characteristic bond strength in uncracked concrete[8]	$\tau_{k,uncr}$	psi (N/mm²)	1,450 (10.0)	1,450 (10.0)	1,450 (10.0)	1,450 (10.0)	1,450 (10.0)	1,305 (9.0)	1,160 (8.0)	1,030 (7.1)

[7]For structures assigned to Seismic Design Categories C, D, E or F, bond strength values for cracked concrete must be adjusted by an additional reduction facto $\alpha_{N,seis}$ = 0.95. See Section 4.1.11 of this report.

Page 45 of European technical approval ETA-13/0258 of 24 April 2013

English translation prepared by DIBt

Deutsches Institut für Bautechnik DIBt

Table 39: Reduction factors for seismic performance category C1 for threaded rods

Anchor size threaded rod			M 12	M 16	M 20	M24	M 27	M 30
Tension load								
Steel failure								
Seismic reduction factor	$\alpha_{N,seis}$	[-]	1,0					
Combined pullout and concrete cone failure								
Seismic reduction factor	$\alpha_{N,seis}$	[-]	0,68	0,68	0,68	0,69	0,69	0,69
Shear load								
Steel failure without lever arm								
Seismic reduction factor	$\alpha_{V,seis}$	[-]	0,70					

- Reduction of steel strength in shear
- Reduction of pullout strength in tension

Note: For adhesive anchor, pullout strength = bond strength

Background and brief history of seismic anchor approval

Seismic anchor regulations in Europe and US

	Qualifcation Guideline	**Technical Approval (Evaluation Report)**	**Design Guideline**
EUROPE	ETAG 001 + **ETAG 001 Annex E**	European Technical Approval **(ETA)**	ETAG 001 Annex C + **EOTA TR 045 (seismic)**
Latest changes	EAD mech&adh anchor + EOTA TR seismic anchor	→ European Technical *Assessment* (ETA)	CEN-TS 1992-4 (2009) ↓ EN 1992-4 (EC2 Part 4)
USA	ACI 355.2 and ACI 355.4 AC 193 and AC 308	ICC-ES (ESR)	ACI 318-11 Appendix D

Background and brief history of seismic anchor approval

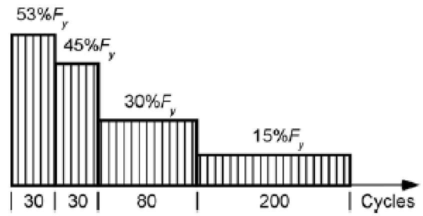
Simulated seismic tests: US / Candu

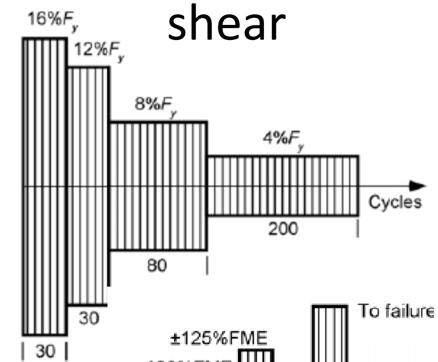
USA/CAN

tension

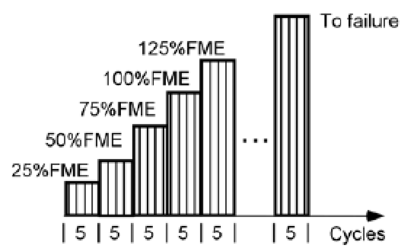
shear

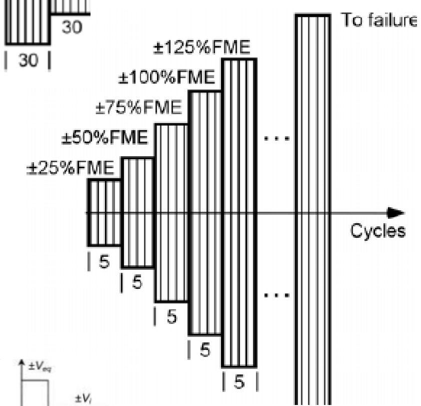
CAN/CSA-N287.2 (1991)
340 load cycles in
uncracked concrete



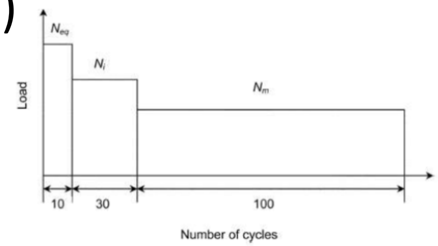


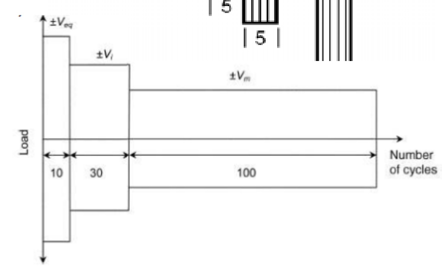
SEAOSC (1997)
20 to 30 load cycles in
uncracked concrete





ACI 355.2 (2001) / ACI355.4 (2011)
140 load cycles in
cracked concrete (0.5 mm)





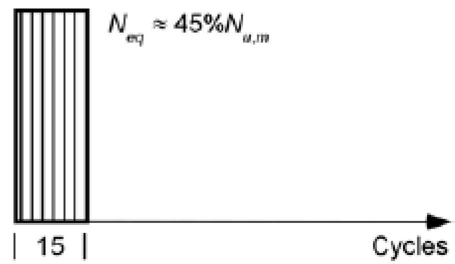
Background and brief history of seismic anchor approval

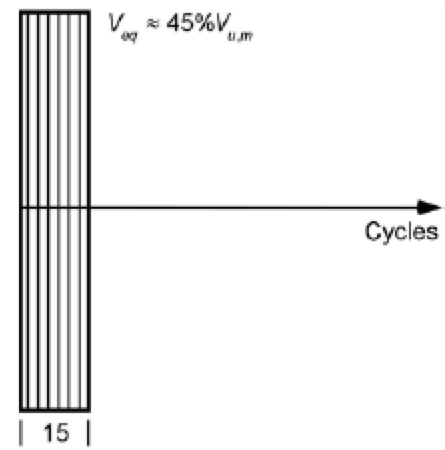
Simulated seismic tests: Germany

EUR/GER

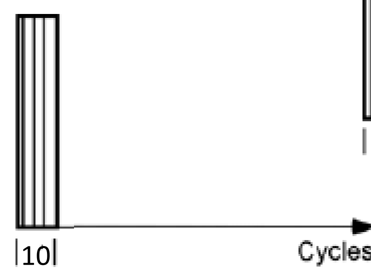
tension | shear

DIBt NPP guideline (1998)
15 load cycles in
cracked concrete (1.5 mm)



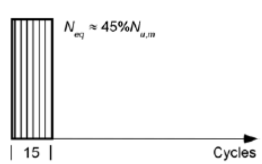


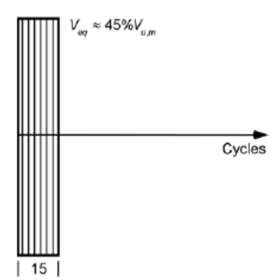
In addition tests with cycled cracks:
10 crack cycles (between 1.0 and 1.5 mm)
while anchor permanently loaded



suitability

Further tests to determine
characteristc strength in 1.0 mm



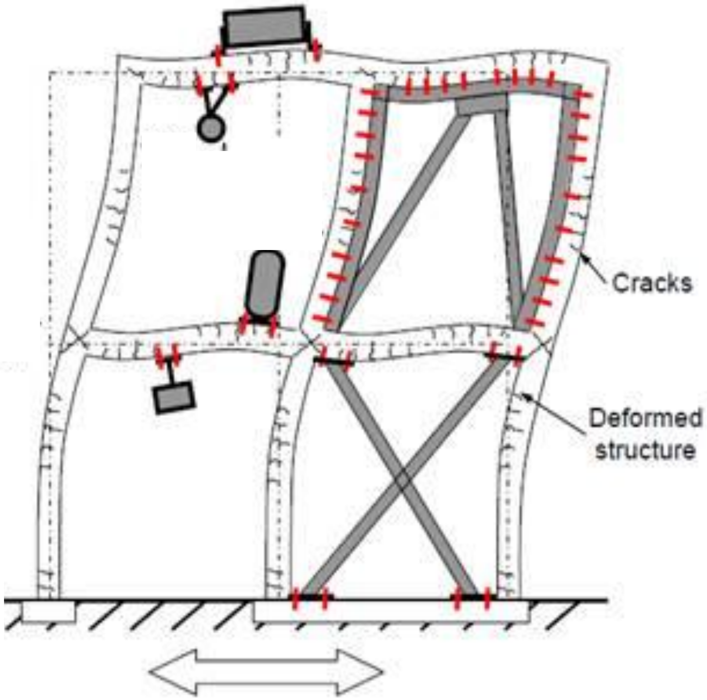


serviceability

Background and brief history of seismic anchor approval

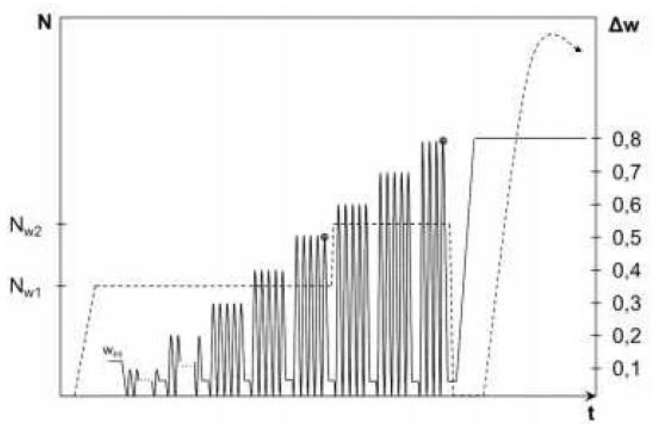
Questions playing role in development of scientifically substantiated European seismic qualification guideline:

nonstructural & structural connections



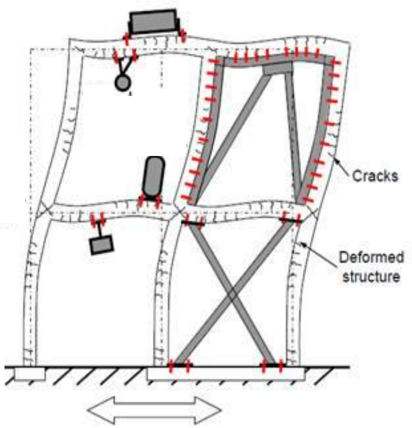
- Crack width: what is the seismic crack width?
- Load cycling: - which number of load cycles?
  - what pattern of load cycles?
- Crack cycling: - which number of load cycles?
  - what pattern of load cycles?
- How to test anchor performance on serviceabaility and on suitability level?

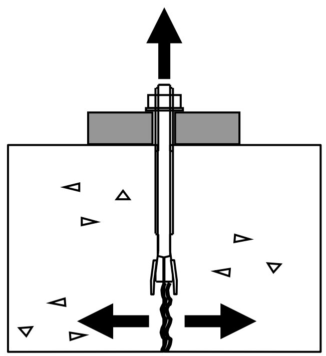
Development of the new European seismic C2 qualification

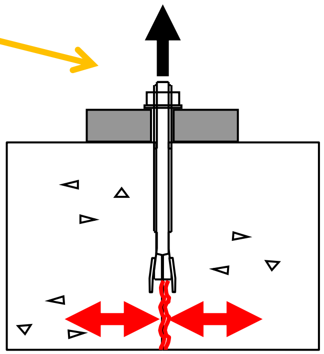


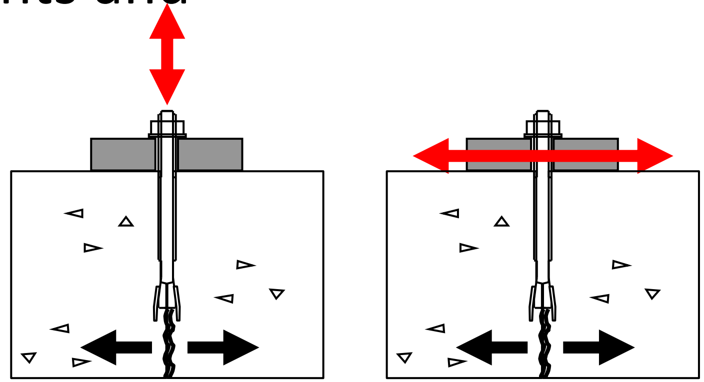
Development of the new European seismic C2 qualification

Characteristics of actions during seismic events and how to test them on anchors









Load cycling tests:

- cyclic load on anchor in
- static crack

Crack cycling tests:

- permanent load on anchor in
- cyclic crack

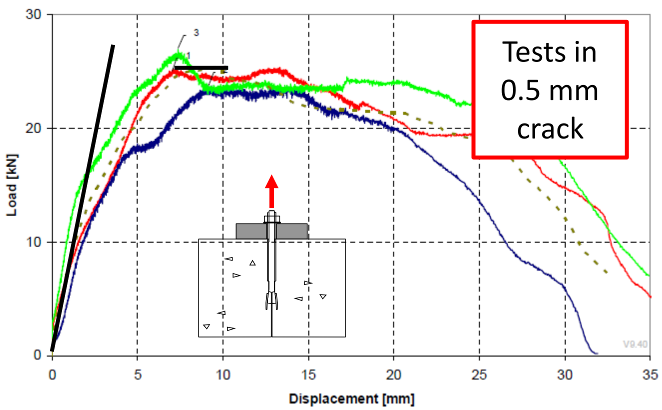
Monotonic tests:

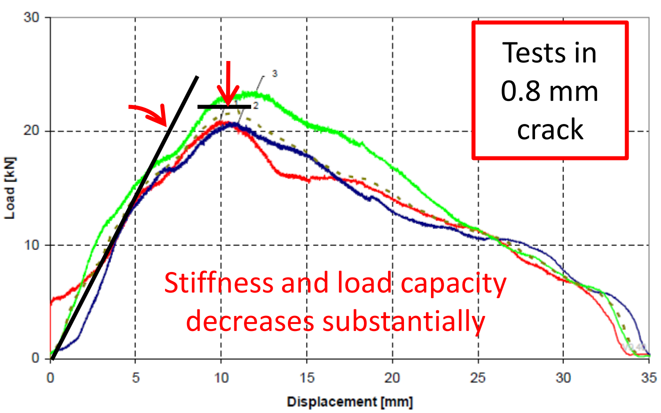
- quasi-static load on anchor in
- static crack

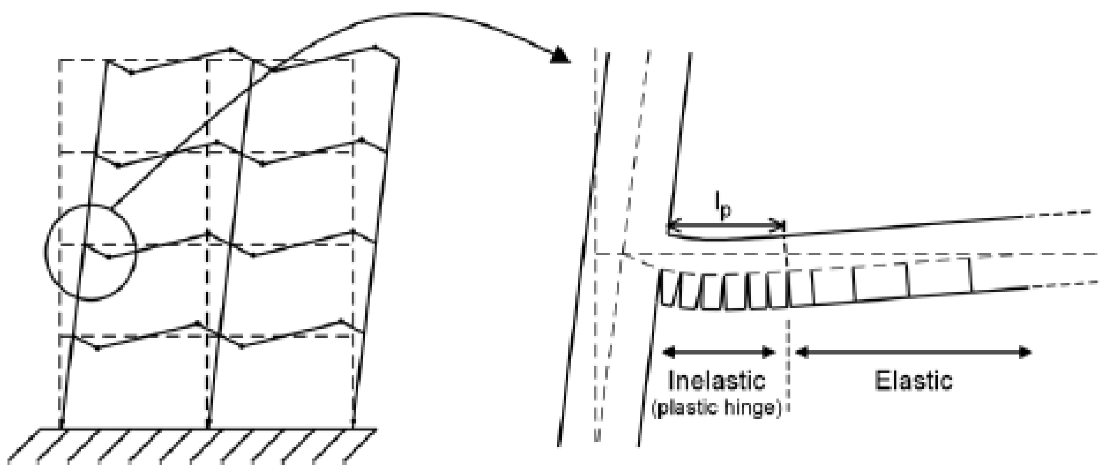
Large number of small amplitude cycles, but only moderate number of pronounced load and crack cycles

Development of the new European seismic C2 qualification

Critical crack width in RC structures during earthquakes





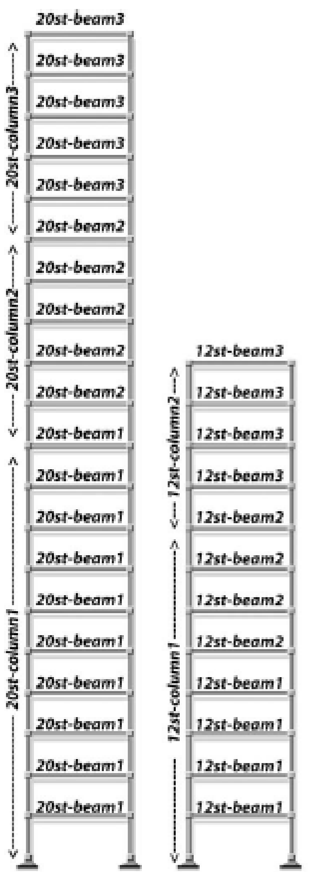


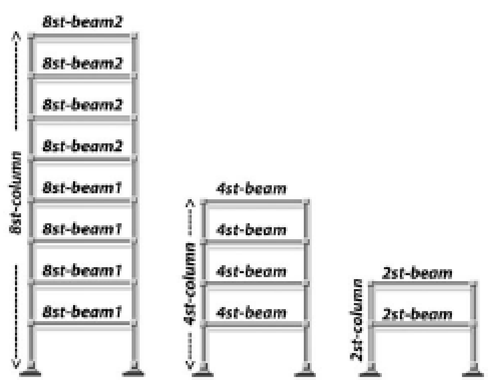
Taken from: M. Hoehler (2006): Behavior and Testing of Fastenings to Concrete for use in Seismic Applications

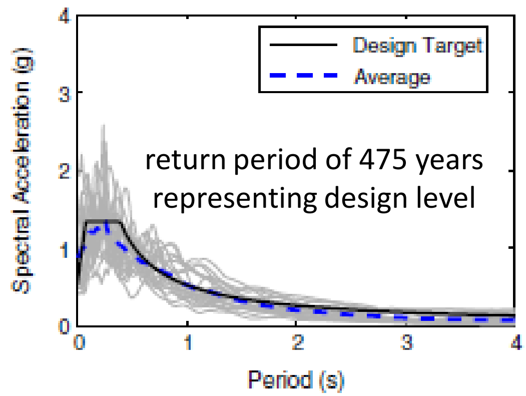
Maximum crack width outside of plastic hinge zones: 0.8 mm

Development of the new European seismic C2 qualification

Nonlinear simulations of RC typical structures stock





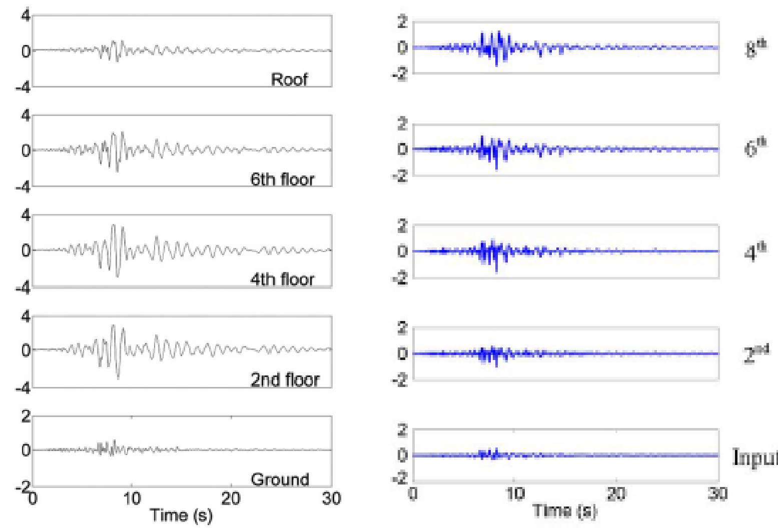


after: R. Wood & T. Hutchinson(2013)

7 building types subjected to 20 scaled ground motions

↓

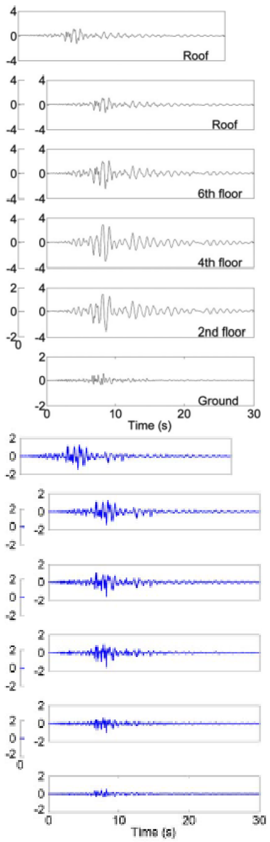
966 time histories generated for <u>curvature</u> and <u>floor acceleration</u>



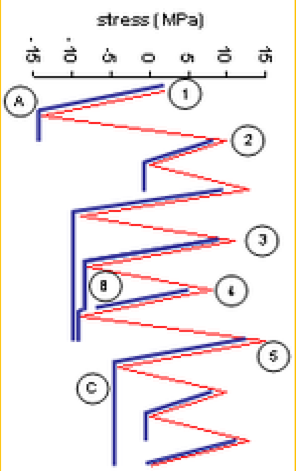
Example hstories for 8 story building; Northridge 1994 ground motion

Development of the new European seismic C2 qualification

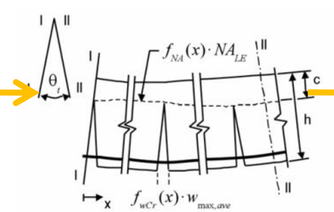
Processing of the nonlinear curvature and acceleration data



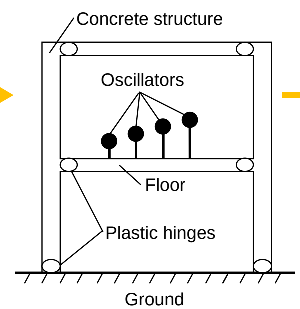
→ Rainflow counting algorithm



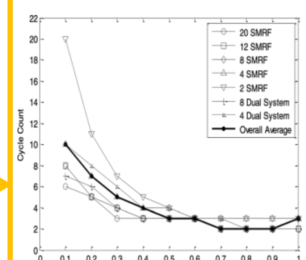
→ Curvature → crack width



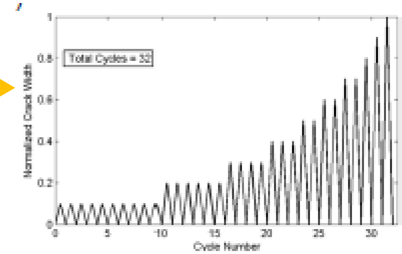
→ SDOF oscill. → anchor load



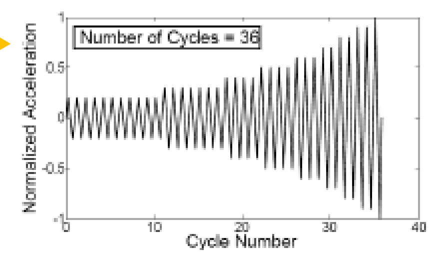
→ Combination per buidling & Overall building ave.



→ Crack protocol



→ Load protocol

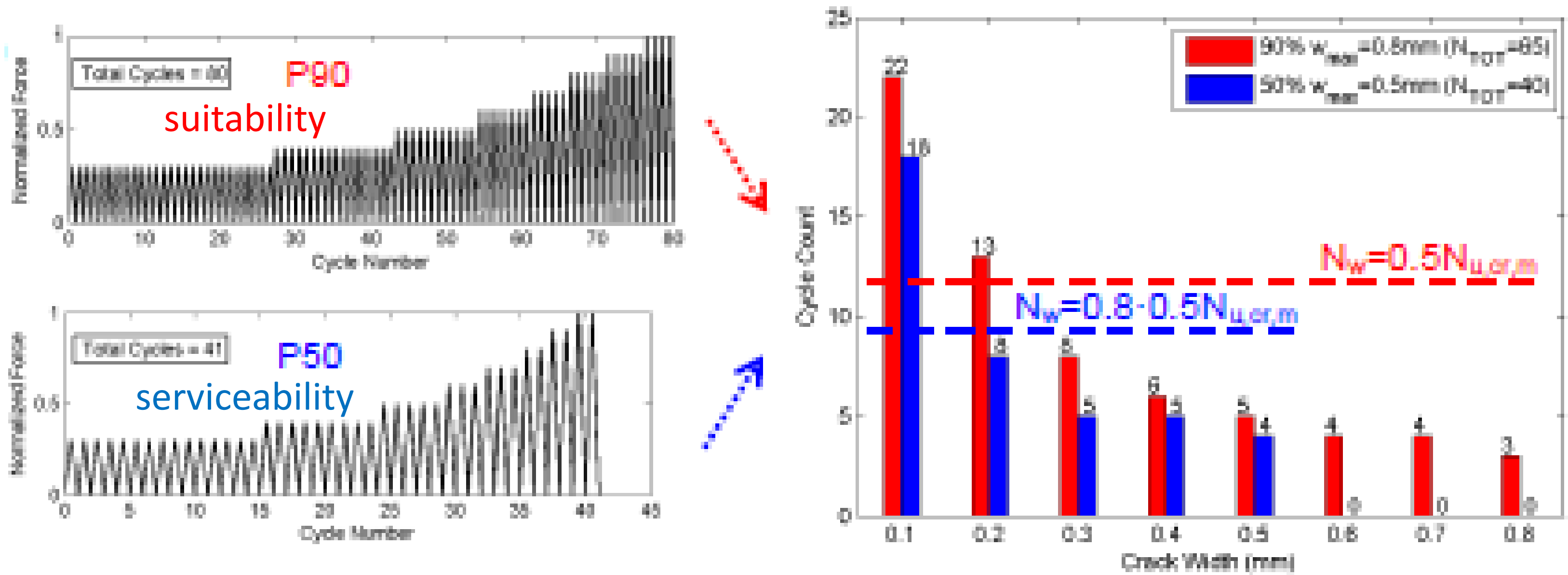


after: R. Wood & T. Hutchinson(2013)

Development of the new European seismic C2 qualification

Development of serviceability level and suitability level test protocols

Example: cyclic crack protocol



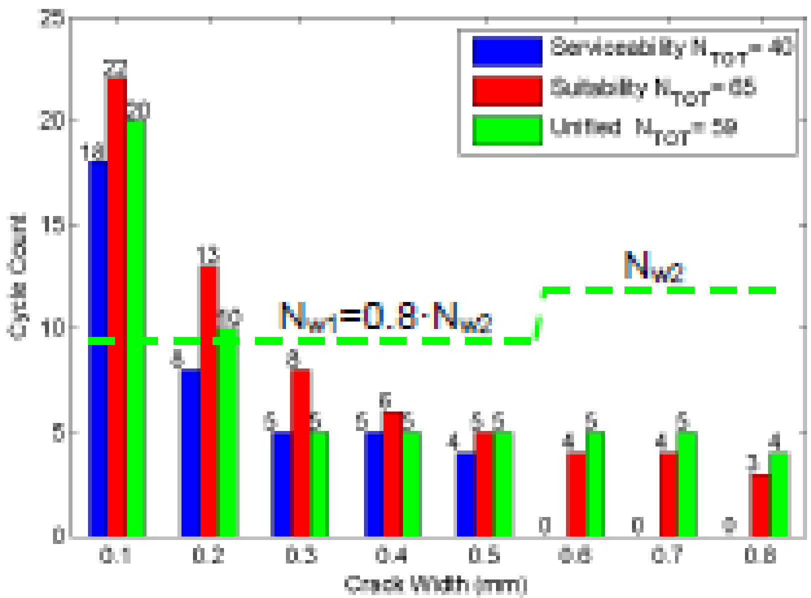
Separate serviceability and suitability protocol results in high testing burden!

→ Combine protocols to one unified protocol allowing evaluation by one test: anchor displacement on serviceability level & ultimate load on suitability level

Development of the new European seismic C2 qualification

Development of unified test protocol and test parameters

Example: cyclic crack protocol



Tension Cycling	Serviceability	Suitability
Static crack width [mm]	0.5	0.8
Target load $[N_{max}/N_{u,cr,m}]$	$0.5 \cdot 0.75 = 0.375$	0.75

Shear Cycling	Serviceability	Suitability
Static crack width [mm]	0.8	0.8
Target load $[V_{max}/V_{u,cr,m}]$	$0.5 \cdot 0.85 = 0.425$	0.85

Crack Cycling	Serviceability	Suitability
Target crack width [mm]	0.5	0.8
Permanent load $[N_w/N_{u,cr,m}]$	$0.8 \cdot 0.5 = 0.4$	0.5

→ **0.8 mm** crack width for adverse condition / extreme EQ event: **suitability** level
→ **0.5 mm** crack width for service condition / moderate EQ event: **serviceability** level

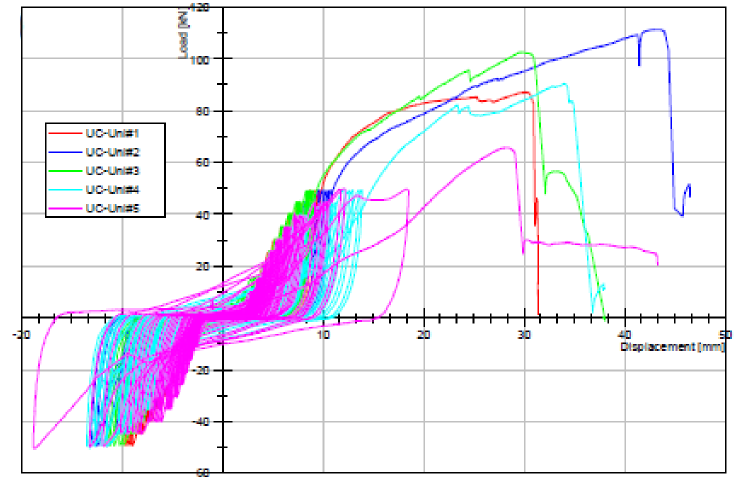
→ Permanent anchor load at **serviceability** level = **0.8 times** anchor load at **suitability** level

Development of the new European seismic C2 qualification

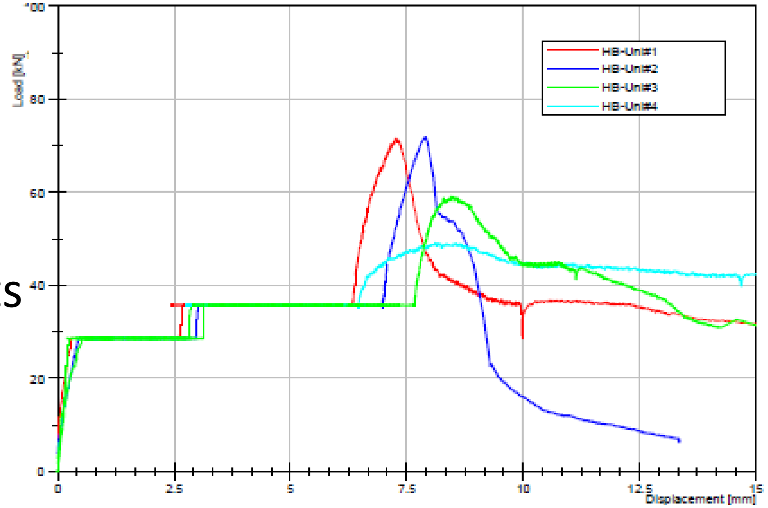
Verification by experimental tests

State-of-the-art test setup

Cyclic load tests



Cyclic crack tests

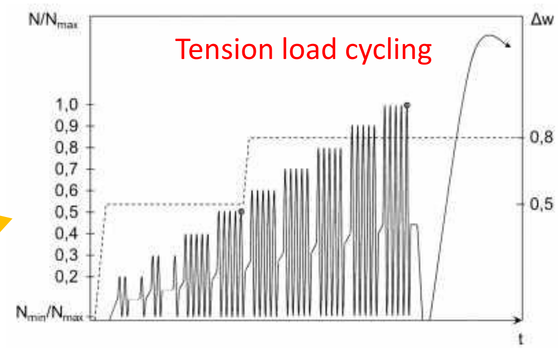


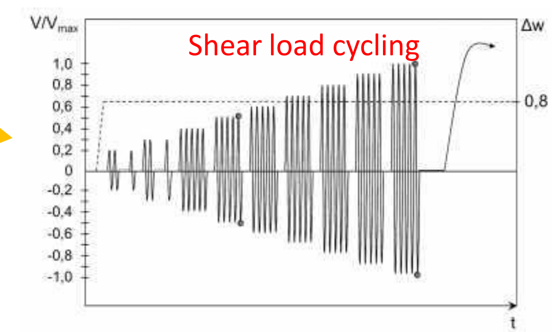
Development of the new European seismic C2 qualification

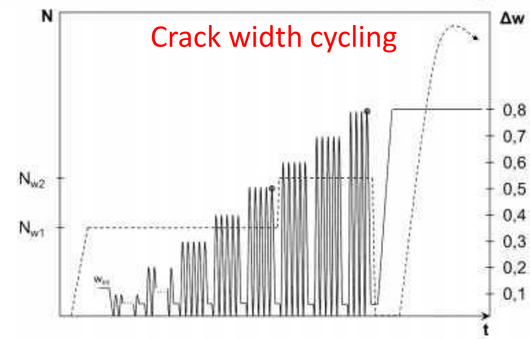
Final load and crack cycling protocol as in ETAG 001 Annex E

Anchorload F/F_{max}	Number of cycles	Crack width Δw [mm]
0,2	25	0,5
0,3	15	0,5
0,4	5	0,5
0,5	5	0,5
0,6	5	0,8
0,7	5	0,8
0,8	5	0,8
0,9	5	0,8
1	5	0,8
SUM	75	

Crack width Δw [mm]	Number of cycles	Anchor load
0,1	20	N_{w1}
0,2	10	N_{w1}
0,3	5	N_{w1}
0,4	5	N_{w1}
0,5	5	N_{w1}
0,6	5	N_{w2}
0,7	5	N_{w2}
0,8	4	N_{w2}
SUM	59	

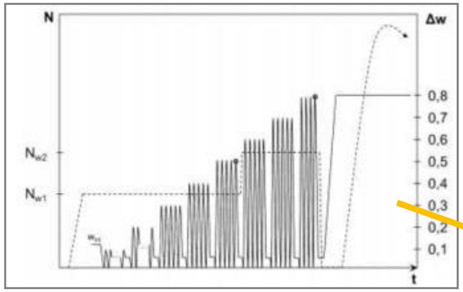


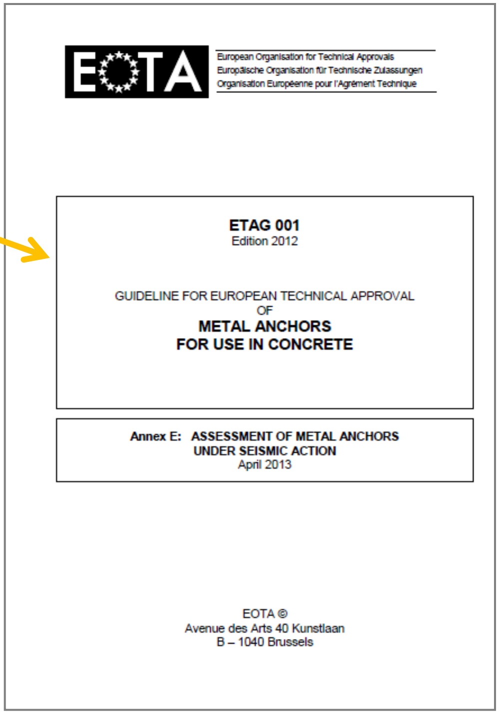




Development of the new European seismic C2 qualification

ETAG 001 Annex E

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ETAG 001
Edition 2012

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL
OF
METAL ANCHORS
FOR USE IN CONCRETE

Annex E: ASSESSMENT OF METAL ANCHORS UNDER SEISMIC ACTION
April 2013

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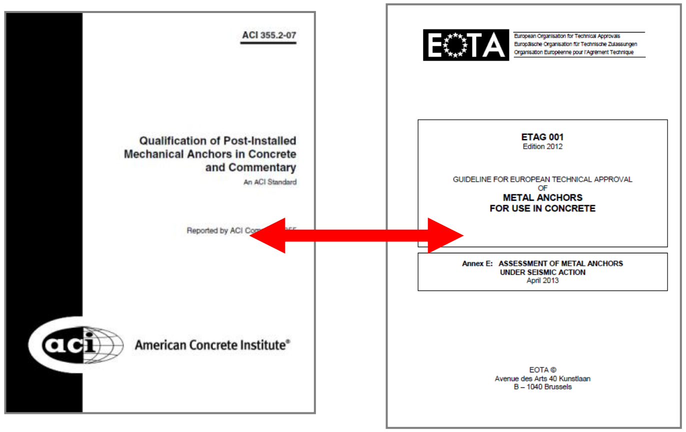
Avenue des Arts 40 Kunstlaan
B – 1040 Brussels

- Conclusive protocol set for **anchor load and crack width** cycling tests and corresponding reference tests
- Comprehensive investigation of critical **test parameters**
- Unified protocols allow evaluation of **serviceability and suitability level performance**
- **Stepwise increasing** protocols allow evaluation of anchor performance with increasing demand

Further reading: Mahrenholtz (2012): Experimental Performance and Recommendations for Qualification of Post-installed Anchors for Seismic Applications, Dissertation

Comparison ACI 355 and ETAG C1/C2 seismic qualification



Comparison ACI 355 and ETAG C1/C2 seismic qualification

Seismic qualification (w = crack width)

	ACI 355	ETAG C1	ETAG C2
Anchor load cycling Tension	- Cyclic tests (w = 0.5 mm)	- Cyclic tests (w = 0.5 mm)	- Cyclic tests (w_{max} = 0.8 mm)
Shear	- Cyclic tests (w = 0.5 mm)	- Cyclic tests (w = 0.5 mm)	- Cyclic tests (w_{max} = 0.8 mm)
Crack width cycling	- Crack movement tests (w_{max} = 0.3 mm)	- Crack movement tests (w_{max} = 0.3 mm)	- Cyclic tests (w_{max} = 0.8 mm)
Reference tests Tension	Included in static ESR	Included in static ETA	- Monotonic tests (w = 0.8 mm)
Shear			- Monotonic tests (w = 0.8 mm)

Comparison ACI 355 and ETAG C1/C2 seismic qualification

Equivalency of ACI 355 and ETAG 001 C1 seismic qualification

ACI 355

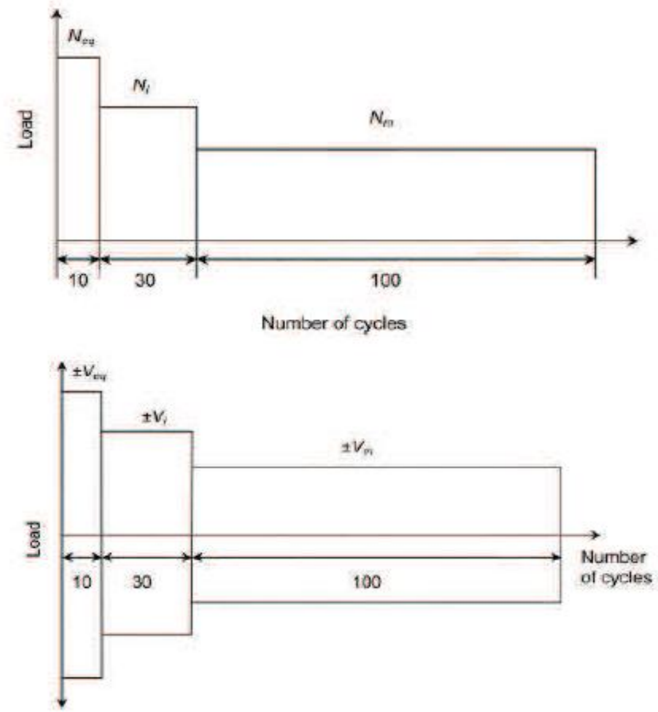


Figure 4. Test protocol for simulated seismic tests according to ACI 355 for tension loading (top) and shear loading (bottom).

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ETAG C1

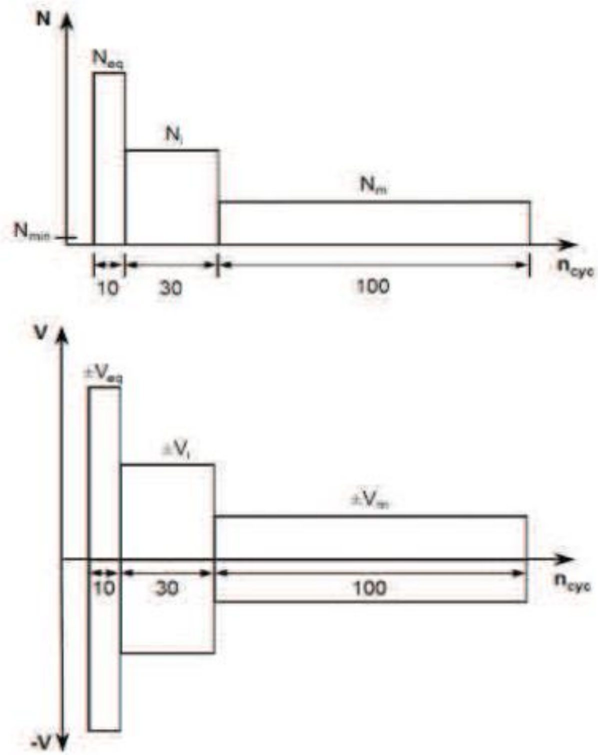

Figure 6. Test protocol for simulated seismic tests according to ETAG 001 Annex E for tension loading (top) and shear loading (bottom).

Comparison ACI 355 and ETAG C1/C2 seismic qualification

Recommended performance categories for seismic anchors

→ ETAG 001 Annex E and EOTA TR 045 define 2 seismic performance categories:

- C1 corresponds to seismic qualification according to ACI 355
- C2 for more extreme earthquakes

Seismicity		Importance Class acc. to EN 1998-1:2004, 4.2.5			
	$a_g \cdot S$ [2]	I	II	III	IV
Very low[1]	$a_g \cdot S \le 0{,}05\ g$	ETAG 001 Part 1 to Part 5			
Low[1]	$0{,}05\ g < a_g \cdot S \le 0{,}1\ g$	C1	C1 [3] nonstructural or C2 [4] structural		C2
	$a_g \cdot S > 0{,}1\ g$	C1	C2		

→ Recommendation depends on:

- Importance of building (similar to occupancy category)
- Seismicity, i.e. design ground acceleration

Comparison ACI 355 and ETAG C1/C2 seismic qualification

Equivalency of ACI 355 and ETAG 001 C1 seismic qualification

ACI 318

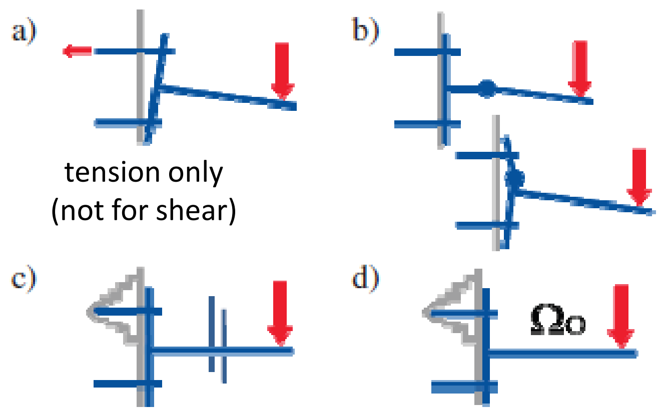

Figure 8. Design options for anchors according to ACI 318 Appendix D: (a) Ductile anchor design; (b) Capacity design; (c) Maximum force design; (d) Elastic design.

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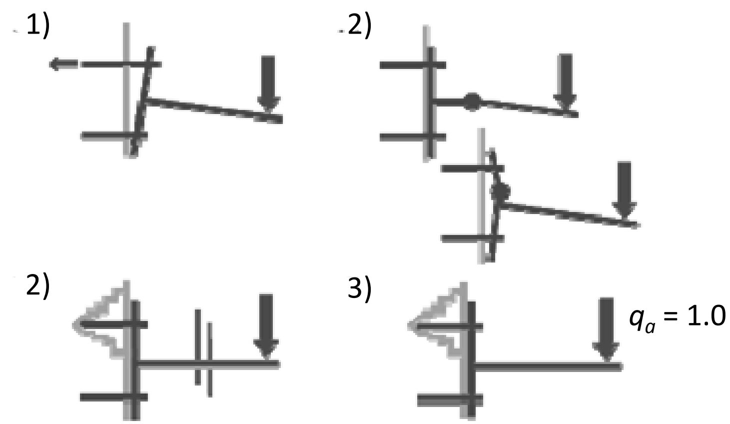
EOTA TR 045



1) Ductile anchor design (TR 045 5.3 (b))
2) Capacity design (TR 045 5.3 (a1))
3) Elastic design (TR 045 5.3 (a2))

For load combinations which earthqake component is more than 20%

Comparison ACI 355 and ETAG C1/C2 seismic qualification

Equivalency of elastic response spectra given in ASCE 7 and EN 1998

ASCE 7

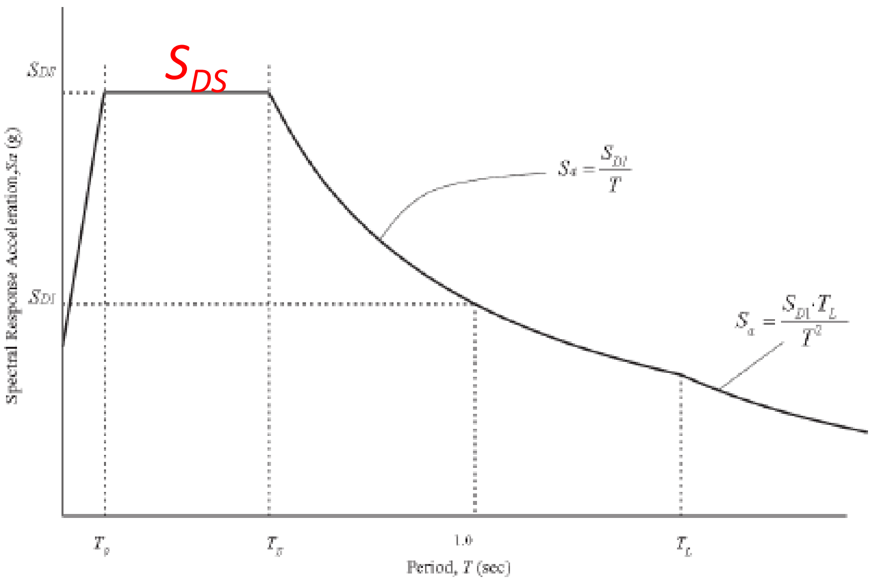


Figure 10. Elastic response spectra according to ASCE 7.

≈

EN 1998 (EC8)

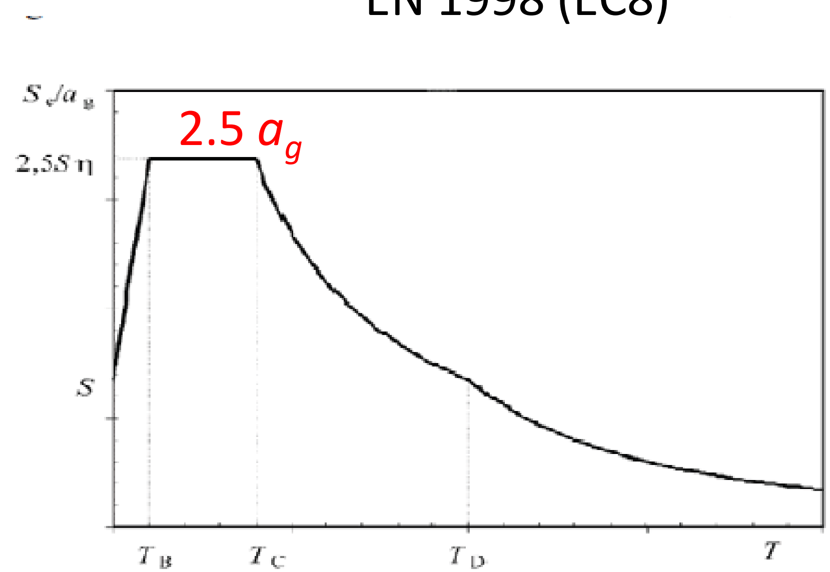


Figure 11. Elastic response spectra according to Eurocode 8.

For example acceleration for rock ground type (soil factor S = 1.0): S_{DS} = 2.5 a_g

Comparison ACI 355 and ETAG C1/C2 seismic qualification

Comparison of required seismic qualification for anchors based on the design ground acceleration

$a_g \cdot S$ [2)]	I	II	III	IV
$a_g \cdot S \leq 0{,}05\ g$	ETAG 001 Part 1 to Part 5			
$0{,}05\ g < a_g \cdot S \leq 0{,}1\ g$	C1	C1 [3)] or C2 [4)]		C2
$a_g \cdot S > 0{,}1\ g$	C1	C2		

$S_{DS} = 2.5\ a_g$ (short period, $S = 1.0$)

Table 1. Seismic performance categories for anchors under seismic action after EOTA TR 045 but modified for S_{DS} equivalents.

Seismicity Level Class	$2.5a_g = S_{DS}$*	Importance Class I	II	III	IV
Very Low	$S_{DS} \leqq 0.125\ g$	No additional requirement			
Low	$0.125g < S_{DS} \leqq 0.25\ g$	C1	C1 or C2		C2
> Low	$S_{DS} > 0.25\ g$	C1	C2	C2	C2

* Equivalent S_{DS} value for rock.

Table 2. ACI 318 and EOTA TR 045 requirement for anchor qualification.

Design Ground Acceleration, Short Period Response – S_{DS}	US Seismic Design Category	ACI 318 Requiremt *	European Seismicity Class for Anchors	TR 045 Requiremt **
0.125 g	A	None	Very Low	None
0.126 g	A	None	Low	C1/C2
0.166 g	A	None	Low	C1/C2
0.167 g	B	None	Low	C1/C2
0.250 g	B	None	Low	C1/C2
0.251 g	B	None	>Low	C2
0.332 g	B	None	>Low	C2
0.333 g	C	Seismic	>Low	C2
0.500 g	D	Seismic	>Low	C2

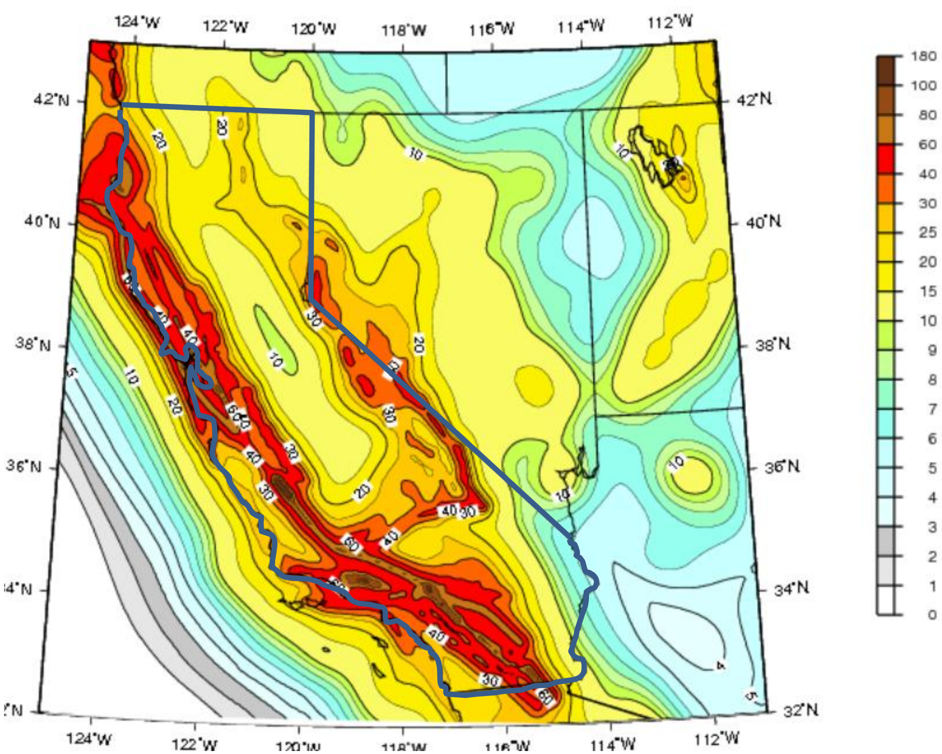
* ‘Seismic’ indicates additional ACI 318 seismic design requirements and ACI 355 qualification is required;
** ‘C1/C2’ indicates ETAG 001 C1 qualification for nonstructural anchorage and C2 qualification for structural anchorage is required; ‘C2’ indicates ETAG 001 C2 qualification for all anchorages is required; additional EOTA TR 045 seismic design requirements for C1 or C2.

Comparison ACI 355 and ETAG C1/C2 seismic qualification

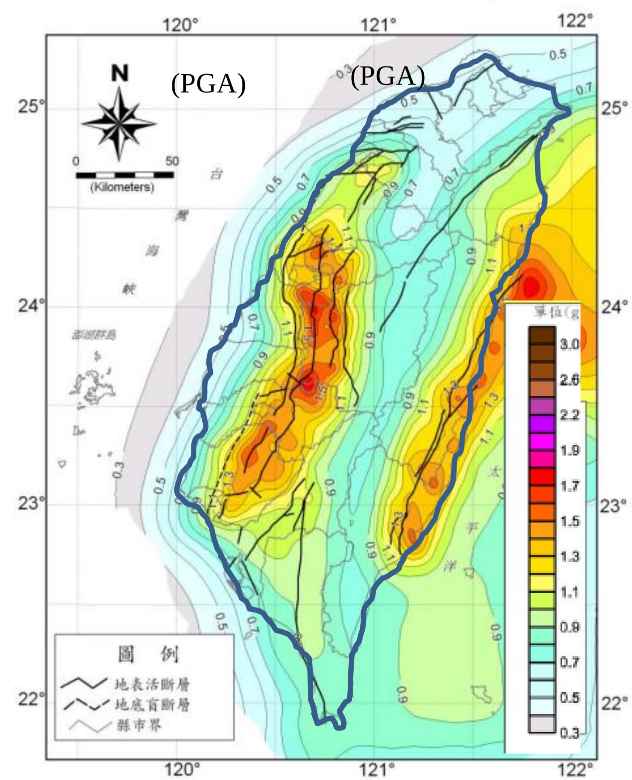
Compare to California and Taiwan

ETAG Annex E	$a_g \cdot S$ [2)]	*I*	*II*	*III*	*IV*
$a_g < 5\%$ g	$a_g \cdot S \le 0{,}05$ g	*ETAG 001 Part 1 to Part 5*			
5% g < $a_g < 10\%$ g	$0{,}05\ g < a_g \cdot S \le 0{,}1$ g	*C1*	*C1* [3)] *or C2* [4)]		*C2*
$a_g > 10\%$ g	$a_g \cdot S > 0{,}1$ g	*C1*	*C2*		

Peak Acceleration (%g) with 10% Probability of Exceedance in 50 Years
USGS Map, Oct. 2002rev



10% Prob. of Exceedance in 50 years

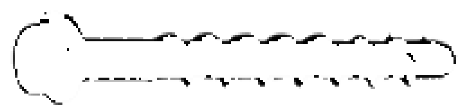


Comparison ACI 355 and ETAG C1/C2 seismic qualification

Seismic anchors approved acc. to ACI 355.2 ACI 355.4 (ESR - inch sizes)

Comparison ACI 355 and ETAG C1/C2 seismic qualification

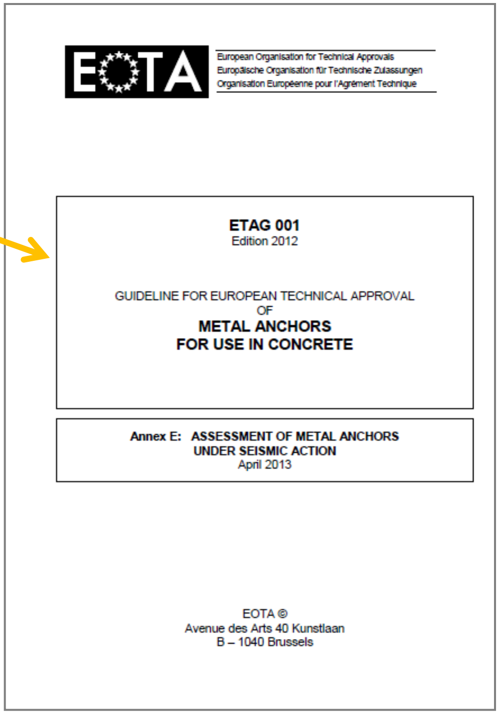
Seismic anchors approved acc. to ETAG 001 C1/C2 (ETA - metric sizes)

C1 approved	 More to come  PB-PRO	 
C1 and C2 approved	 PTB-PRO	

Comparison ACI 355 and ETAG C1/C2 seismic qualification

ETAG 001 Annex E

Seismicity level[a]		Importance Class acc. to EN 1998-1:2004, 4.2.5			
Class	$a_g \cdot S$ [c]	I	II	III	IV
Very low[b]	$a_g \cdot S \leq 0{,}05\,g$	No additional requirement			
Low[b]	$0{,}05\,g < a_g \cdot S \leq 0{,}10\,g$	C1	C1 [d] or C2 [e]		C2
> low	$a_g \cdot S > 0{,}10\,g$	C1	C2		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ETAG 001
Edition 2012

GUIDELINE FOR EUROPEAN TECHNICAL APPROVAL
OF
METAL ANCHORS
FOR USE IN CONCRETE

Annex E: ASSESSMENT OF METAL ANCHORS
UNDER SEISMIC ACTION
April 2013

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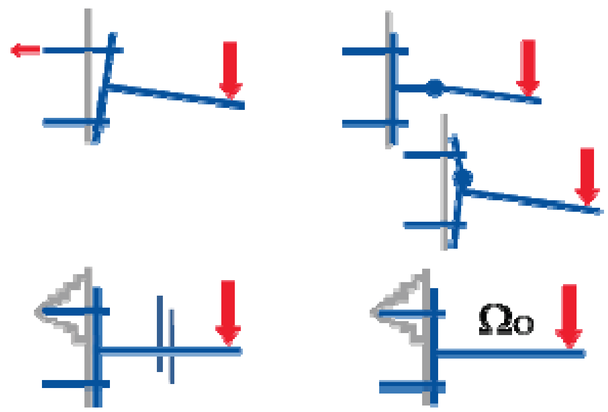
- Concept for resisting seismic loads in **design codes ACI 318 and EOTA TR 045** is very **similar** for anchors
- **ETAG 001 C2 qualification** address **extreme** seismic events beyond the scope of **ACI 355 or C1 qualification**
- Current **EOTA TR 045** mandates **C2 qualification** for anchorage starting at relatively low design accelerations
- Requirements stipulated in EN 1992-4 still under debate for better harmonization within Europe and US

Further reading: Mahrenholtz and Olsen (2014): Brief Comparison of US and European Regulations for the Qualification and Design of Seismic Anchors, IALCCE'14 conference paper

Notes on seismic anchor design



Notes on seismic anchor design

Basic concept of seismic anchor design

Qualification

↓

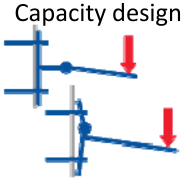
Technical Approval

↓

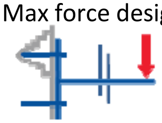
Design

Design without requirement on **anchor ductility**	**Design with** requirement on **anchor ductility**

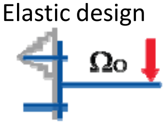
Capacity design



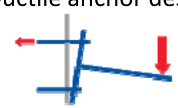
Max force design



Elastic design



Ductile anchor design

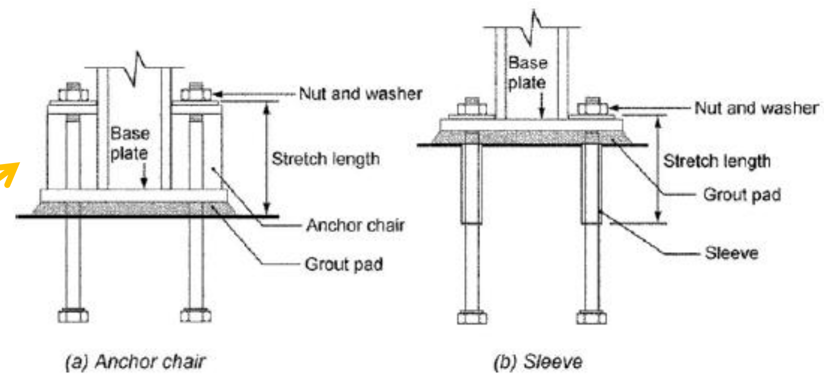


Only tension design!

Requirements:
- N_{sa} x 1.2 < N_{cb}
- Ratio f_{uta}/f_{ya} > 1.3
- Free stretch length 8d

Additional requirement in Europe:
- **C2 qualification**

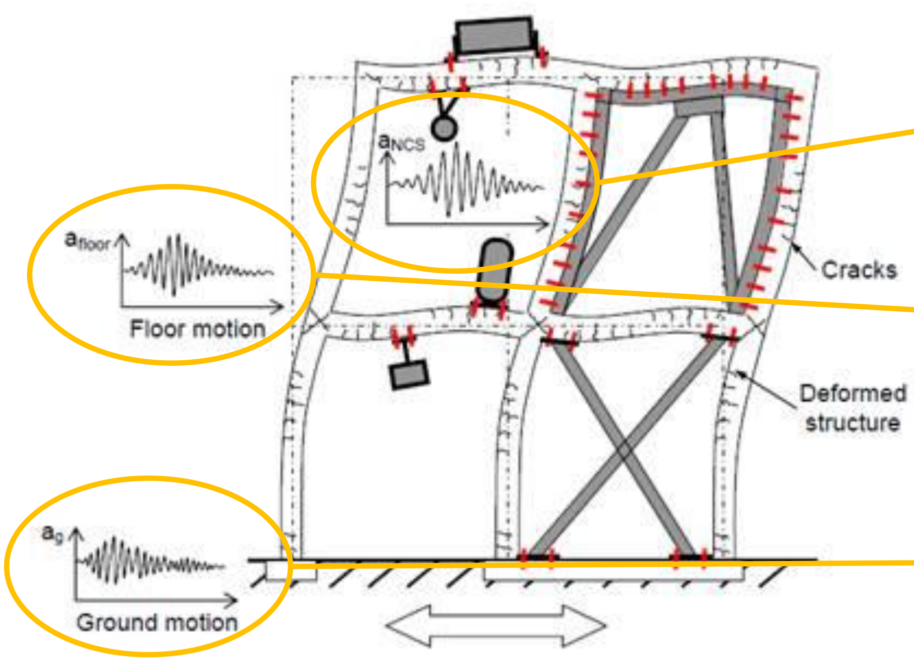
ACI 318 detail for free stretch length ("Chilean design")



→ Requirements for ductile anchor design very demanding

Notes on seismic anchor design

Seismic force from ground level to component level



Seismic forces at component level:
Further amplification

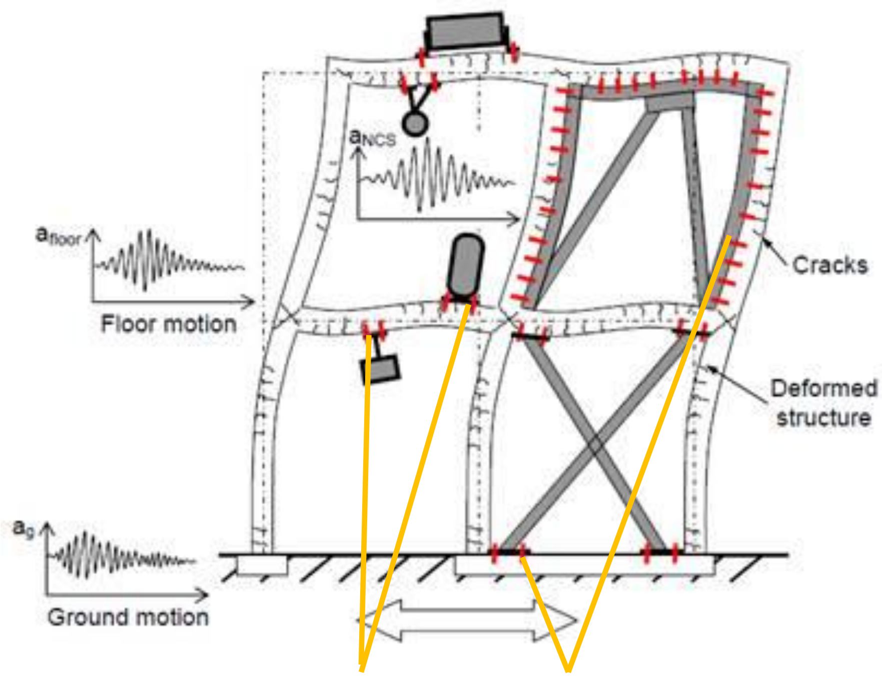
Seismic forces at floor level:
Amplified over height of building

Seismic forces at ground level:
Base shear force

Note: NCS = Nonstructural Components and Systems

Notes on seismic anchor design

Calculation of forces acting on anchor connections



Examples for **nonstructural** connections

Examples for **structural** connections

Forces acting on any **nonstructural** component and their **connections** can be calculated using :

- US: ASCE 7
- Europe: EN 1998 (EC8)

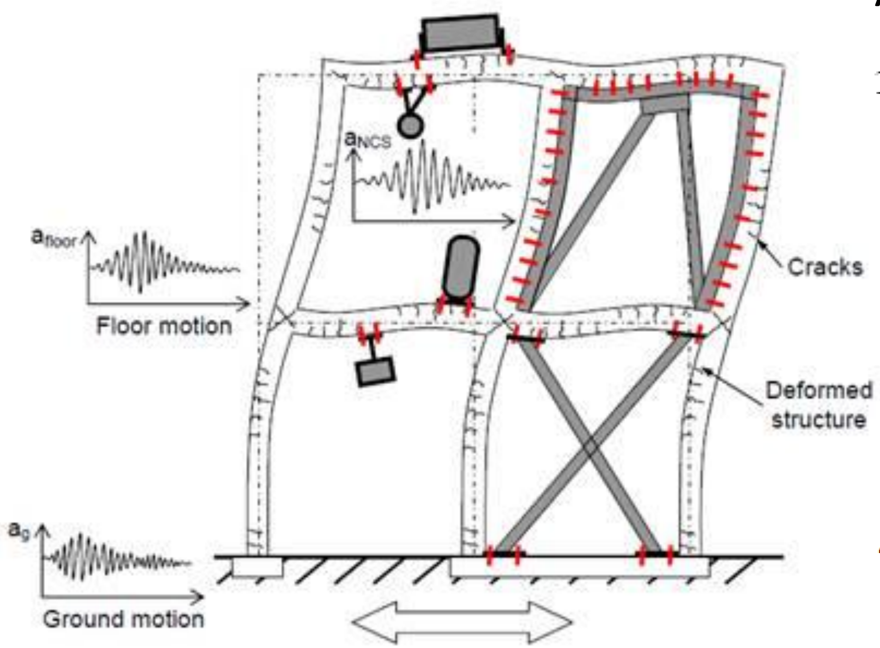
Structural analysis using one of the known methodolgies:

- Equivalent lateral force analysis
- Modal response enalysis
- Time-history analysis

deliver seismic forcesacting on **structural** elements and their **connections** throughout the structure

Notes on seismic anchor design

Seismic forces according to ASCE 7 and EN 1998



F = m · a

ASCE 7

12.8.1 Seismic Base Shear.

$$V = C_s W \qquad (12.8\text{-}1)$$

13.3 SEISMIC DEMANDS ON NONSTRUCTURAL COMPONENTS

13.3.1 Seismic Design Force.

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right) \qquad (13.3\text{-}1)$$

EN 1998 (EC8)

4.3.3.2.2 Base shear force

$$F_b = S_d(T_1) \cdot m \cdot \lambda \qquad (4.5)$$

4.3.5 Non-structural elements

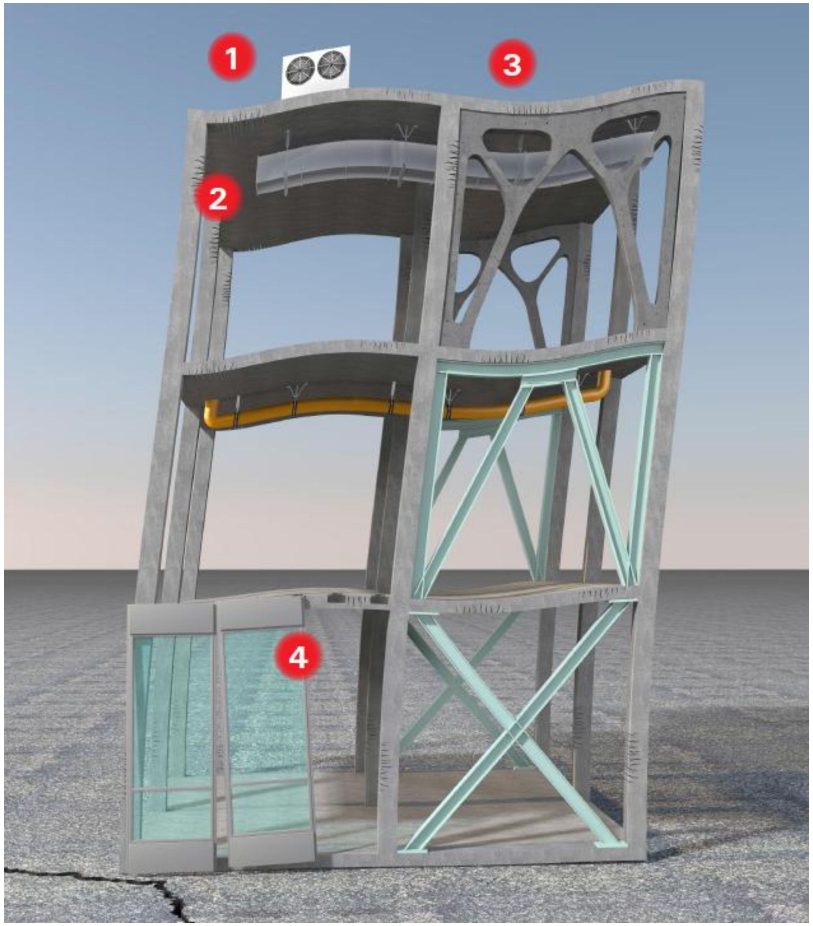
4.3.5.2 Verification

$$F_a = (S_a \cdot W_a \cdot \gamma_a)/q_a \qquad (4.24)$$

$$S_a = \alpha \cdot S \cdot \left[\left(1 + \frac{z}{H}\right) \cdot A_a - 0{,}5\right] \geq \alpha \cdot S$$

Notes on seismic anchor design

Structural and nonstructural applications of anchors



Examples:

1 Floor mounted equipment, e.g. HVAC units

2 Suspended M&E and piping, e.g. sprinkler lines

3 Structural strengthening, e.g. for retrofitting

4 Facade elements, e.g. glass panels and doors

- Protect live
- Limit damage
- Keep civil protection operational

Notes on seismic anchor design

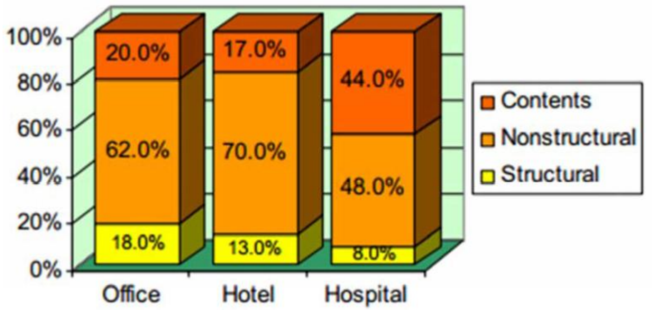
Big structure collapse!

Notes on seismic anchor design

So why do we care about nonstructural anchorage?

Notes on seismic anchor design

Some facts about earthquake damage

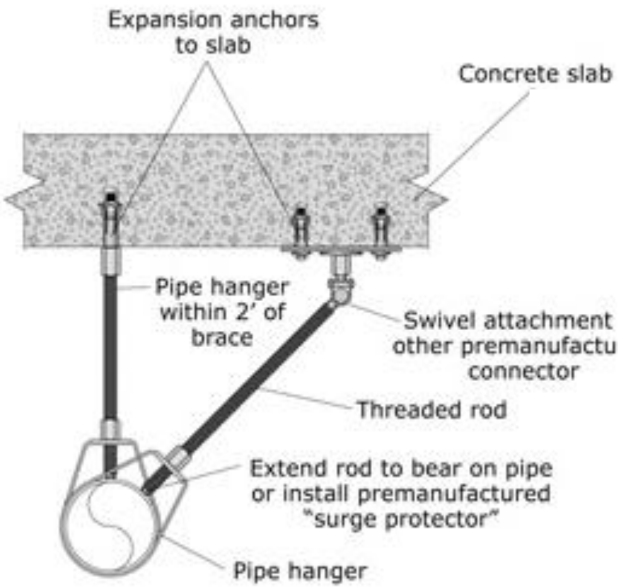


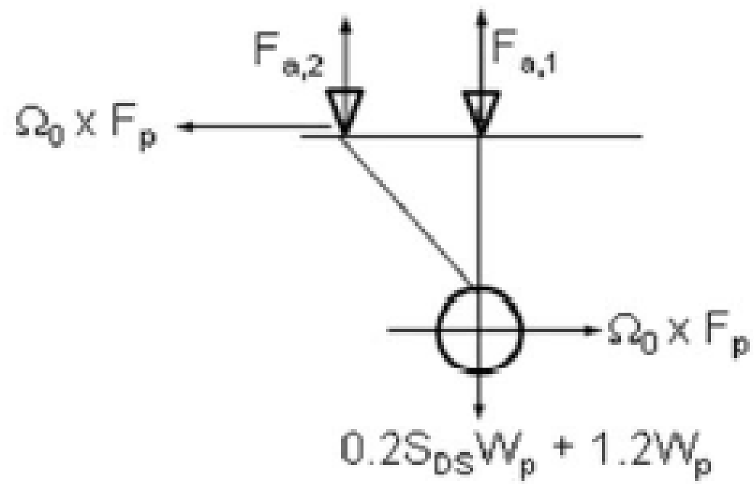
- Considerable portion of EQ damage is caused by wrongly designed or not adequately qualified anchors
- In particular *nonstructural* anchorage is often neglected in design
- 50% of building costs are related to *nonstructural* components
- 30% of all fatilities are attributed to *nonstructural* hazards
- Investment costs for safe seismic anchorage is very low

Notes on seismic anchor design

Design example

Seismic bracing of suspended piping

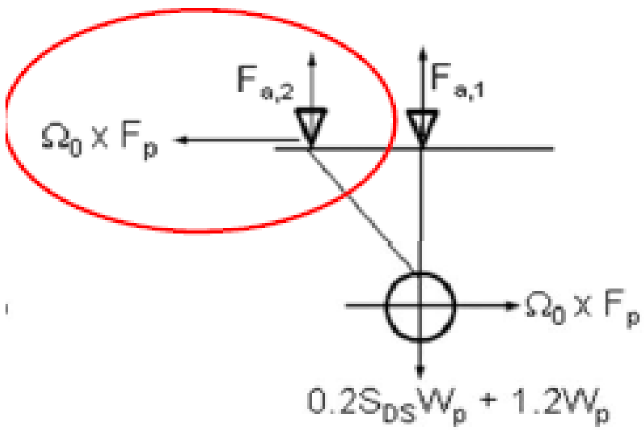




Notes on seismic anchor design

Design example

Calculation of seismic design force



13.3.1 Seismic Design Force. The horizontal seismic design force (F_p) shall be applied at the component's center of gravity and distributed relative to the component's mass distribution and shall be determined in accordance with Eq. 13.3-1:

$$F_p = \frac{0.4a_p S_{DS} W_p}{\left(\frac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right) \qquad (13.3\text{-}1)$$

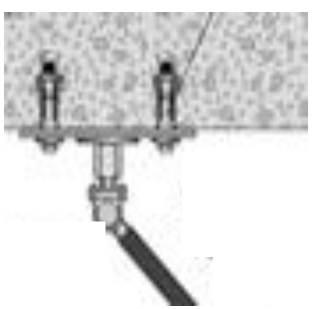


TABLE 13.6-1 SEISMIC COEFFICIENTS FOR MECHANICAL AND ELECTRICAL COMPONENTS

MECHANICAL AND ELECTRICAL COMPONENTS	a_p^a	R_p^b	Ω_0^c
built-in or separate elastomeric snubbing devices or resilient perimeter stops.			
Internally isolated components and systems.	2 ½	2	2 ½
Suspended vibration isolated equipment including in-line duct devices and suspended internally isolated components.	2 ½	2 ½	2 ½
DISTRIBUTION SYSTEMS			
Piping in accordance with ASME B31, including in-line components with joints made by welding or brazing.	2 ½	12	2 ½
Piping in accordance with ASME B31, including in-line components, constructed of high or limited deformability materials, with joints made by threading, bonding, compression couplings, or grooved couplings.	2 ½	6	2 ½

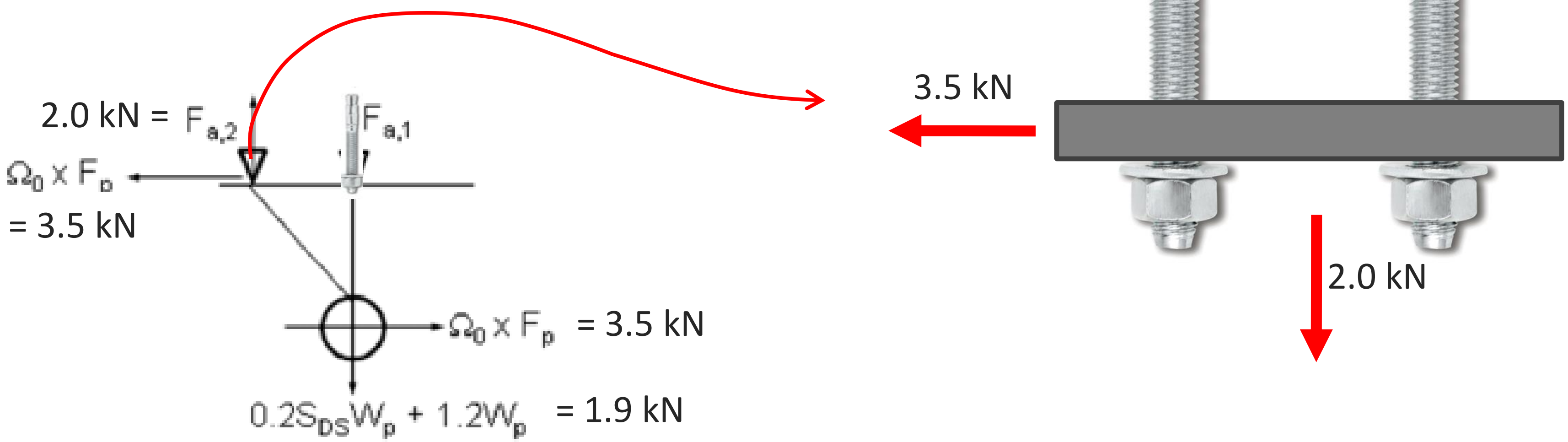
Notes on seismic anchor design

Design example

Elastic design acc. ACI 318 Appendix D

D.3.3.4.3 — Anchors and their attachments shall satisfy one of options (a) through (d):

(d) The anchor or group of anchors shall be designed for the maximum tension obtained from design load combinations that include ***E***, with ***E*** increased by Ω_o. The anchor design tensile strength shall satisfy the tensile strength requirements of D.4.1.1.



Notes on seismic anchor design

Design example

Calculation of seismic design strength

D.3.3.4.4 — The anchor design tensile strength for resisting earthquake forces shall be determined from consideration of (a) through (e) for the failure modes given in Table D.4.1.1 assuming the concrete is cracked unless it can be demonstrated that the concrete remains uncracked:

(a) ϕN_{sa} for a single anchor, or for the most highly stressed individual anchor in a group of anchors;

(b) $0.75\phi N_{cb}$ or $0.75\phi N_{cbg}$, except that N_{cb} or N_{cbg} need not be calculated where anchor reinforcement satisfying D.5.2.9 is provided;

(c) $0.75\phi N_{pn}$ for a single anchor, or for the most highly stressed individual anchor in a group of anchors;

(d) $0.75\phi N_{sb}$ or $0.75\phi N_{sbg}$; and

(e) $0.75\phi N_a$ or $0.75\phi N_{ag}$

where ϕ is in accordance with D.4.3 or D.4.4.

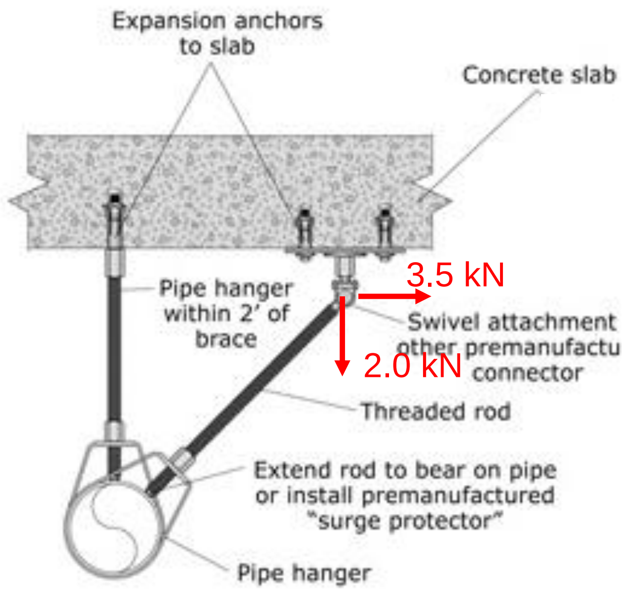
Failure mode	Single anchor	Anchor group*	
		Individual anchor in a group	Anchors as a group
Steel strength in tension (D.5.1)	$\phi N_{sa} \geq N_{ua}$	$\phi N_{sa} \geq N_{ua,i}$	
Concrete breakout strength in tension (D.5.2)	$\phi N_{cb} \geq N_{ua}$		$\phi N_{cbg} \geq N_{ua,g}$
Pullout strength in tension (D.5.3)	$\phi N_{pn} \geq N_{ua}$	$\phi N_{pn} \geq N_{ua,i}$	
Concrete side-face blowout strength in tension (D.5.4)	$\phi N_{sb} \geq N_{ua}$		$\phi N_{sbg} \geq N_{ua,g}$
Bond strength of adhesive anchor in tension (D.5.5)	$\phi N_a \geq N_{ua}$		$\phi N_{ag} \geq N_{ua,g}$
Steel strength in shear (D.6.1)	$\phi V_{sa} \geq V_{ua}$	$\phi V_{sa} \geq V_{ua,i}$	
Concrete breakout strength in shear (D.6.2)	$\phi V_{cb} \geq V_{ua}$		$\phi V_{cbg} \geq V_{ua,g}$
Concrete pryout strength in shear (D.6.3)	$\phi V_{cp} \geq V_{ua}$		$\phi V_{cpg} \geq V_{ua,g}$

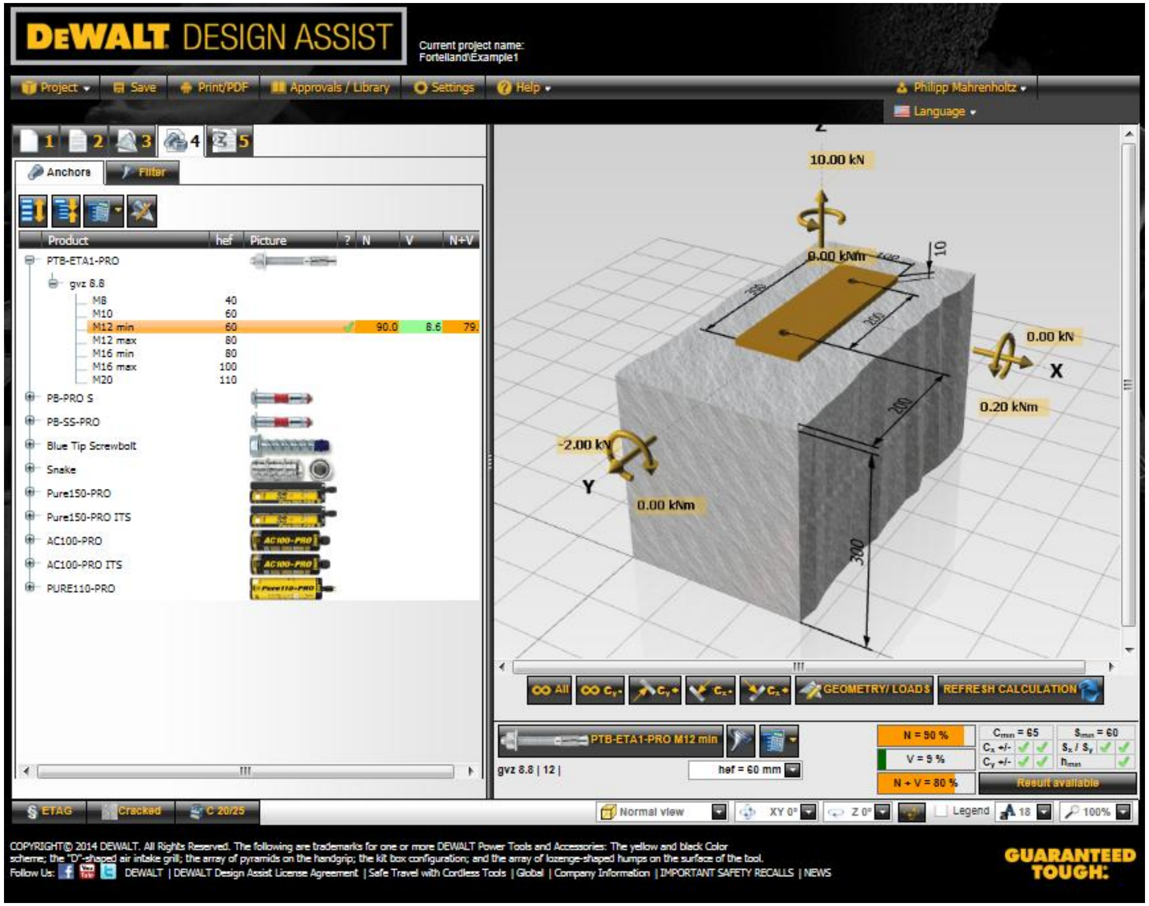
*Required strengths for steel and pullout failure modes shall be calculated for the most highly stressed anchor in the group.

Notes on seismic anchor design

Design example

Use of anchor design software





Key learnings

- Anchor technology and seismic anchoring has a tradition which Powers/Dewalt is a proud part of
- ETAG 001 C2 anchor qualification requirements reflect state-of-the-art knowledge of seismic actions on anchors
- While ETAG 001 C1 is equivalent to ACI 355 seismic qualification, ETAG 001 C2 adds extra safety for extreme seismic events and/or buildings of high importance
- Seismic design of nonstructural anchorage is important yet straight forward with a conclusive design approach

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