SEISMIC ANCHORS ACROSS EUROPE: QUALIFICATION AND DESIGN WITH FOCUS ON FIXING OF NON STRUCTURAL ELEMENTS

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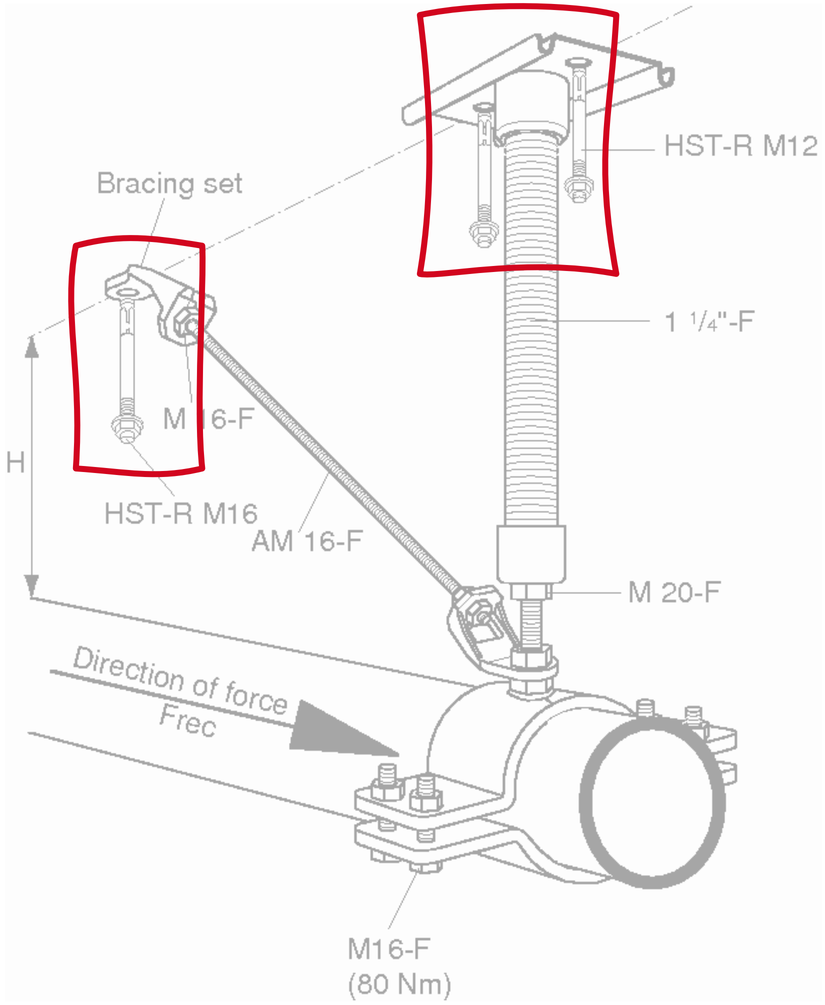
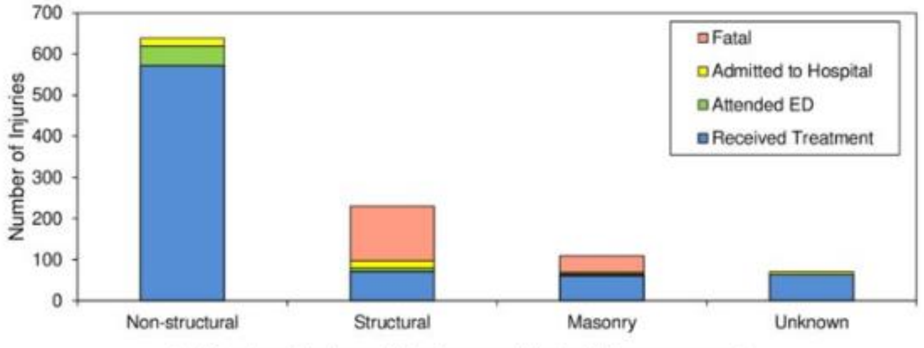
CONTENT



HST-R M12
Bracing set
1 1/4"-F
M 16-F
H
HST-R M16
AM 16-F
M 20-F
Direction of force
Frec
M16-F
(80 Nm)

FAILURE OF NON-STRUCTURAL COMPONENTS IS CAUSE OF ECONOMIC LOSSES, INTERRUPTION OF BUILDING OPERATION, INJURIES AND DEATHS

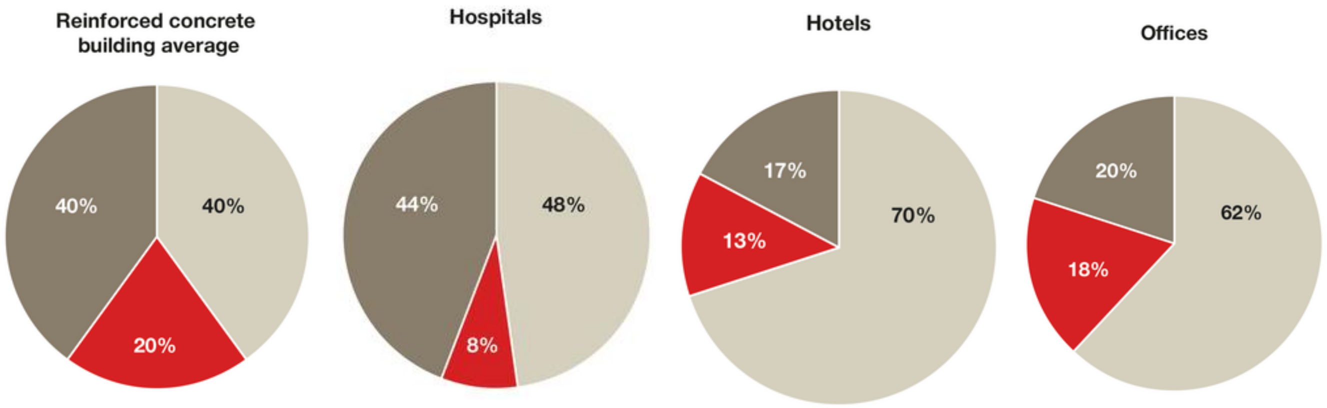
Related injuries



(a) Number of relevant injuries caused by building component

2011 Christchurch Earthquake (source: Yeow et al., 2017)

Economic losses



Source: Taghavi S., Miranda E. «Seismic performance and loss assessment of non-structural building components» - Proccedings 7° National Conference on Earthquake Engineering, Boston 2002

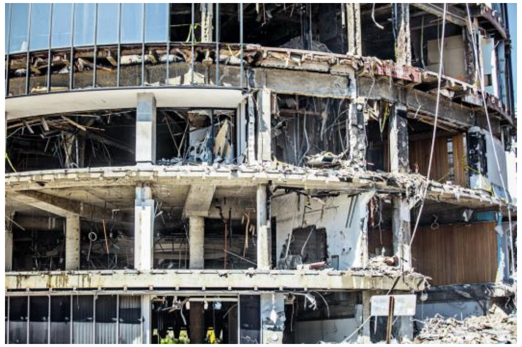
Suspended ceilings

2011 Christchurch Earthquake (source: Yeow et al., 2017)

Machines / Equipment

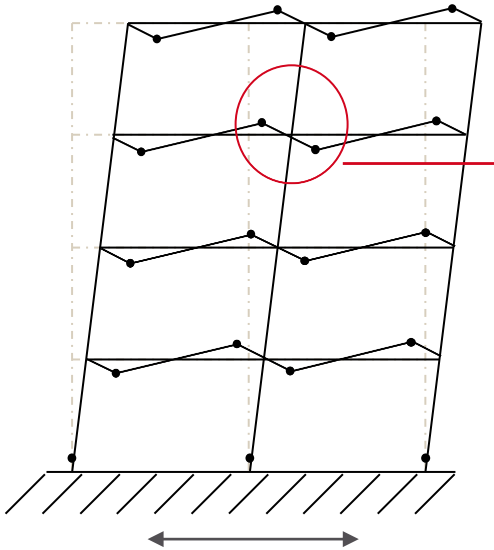
(source: Hilti Corp.)

Façade elements

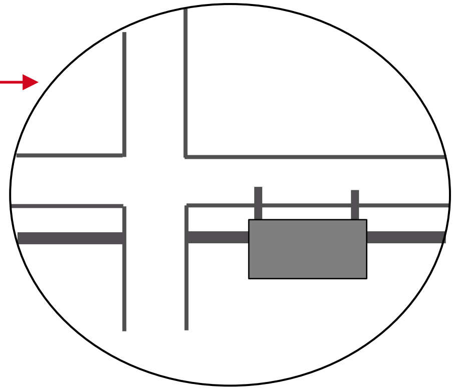


(source: Hilti Corp.)

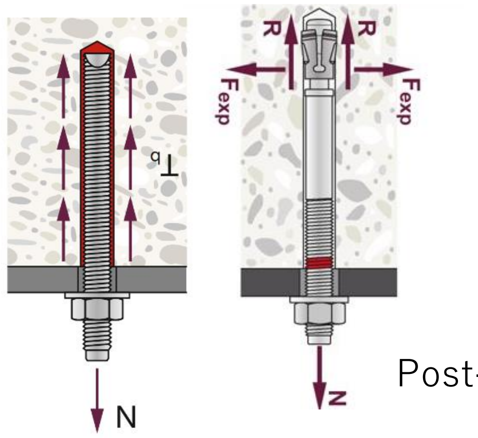
UNDER SEISMIC CONDITIONS THE LOAD-CARRYING BEHAVIOR OF POST-INSTALLED ANCHORS IS SIGNIFICANTLY AFFECTED



Primary structure



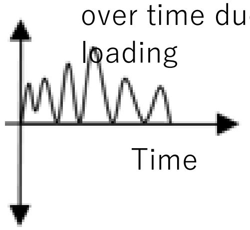
Secondary structure



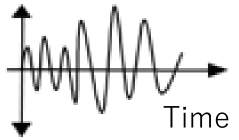
Post-installed anchors

Earthquake ground acceleration

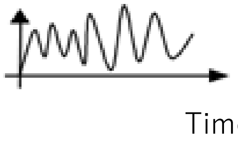
Crack width increase over time due to cyclic loading



Alternating shear

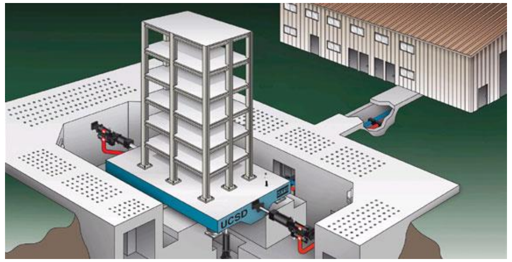


Pulsating tension



INTENSIVE RESEARCH LED TO IMPROVED CONCEPT FOR THE DESIGN OF ANCHORS UNDER SEISMIC LOADING

Large scale testing (Example Multihazard Project (BNCS) San Diego, 2012)



With the shake table testing of a 5-story benchmark building the following questions were addressed:

- Do we need to consider any **critical aspects** in the context with anchor systems to be used under seismic actions?
- Do we need to consider a **crack width larger than 0.5 mm** (limit for static assessment)
- Do we need to consider a **variable crack width** on top to simulated seismic pulsating tension and alternating shear tests?
- How do **crack and load correlate**?
- Do we need to consider **deformation information** in seismic design?

THE BUILDING WAS FULLY EQUIPPED…

Measurement of deformations and crack widths

Cooling tower

Air conditioning

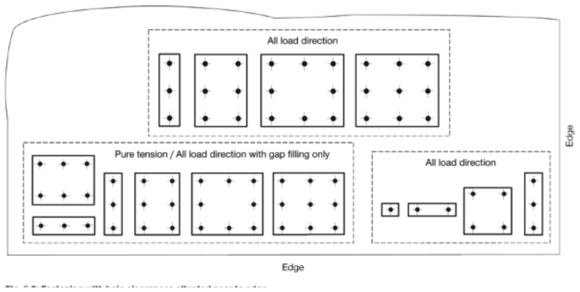
Dry wall / facade panel

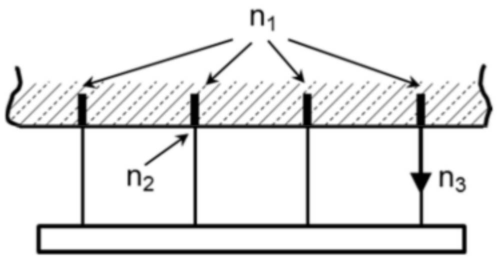
Surgery room

Intensive care unit

Number of other non-structural fastenings

ANCHORING NON-STRUCTURAL ELEMENTS TO CONCRETE CAN FOLLOW TWO MAIN PATHS





	Single point fastenings		Redundant fastenings	
Load	**Static**	**Seismic**	**Static**	**Seismic**
Product Assessment	**EAD 330499 / EAD 330232**		**EAD 330747**	**Not Available**
Technical data	**ETA I**		**ETA II**	
Design method	**EC2-4, Type**	**EC2-4, Annex D**	**CEN/TR 17079**	

Single point fastenings

Minimum diameter of 6 mm and 40 mm embedment.

At least 8-10 mm diameter and 70 mm embedment in typical EOTA seismic assessments

Seismic design according to EN 1992-4

Redundant fastenings

Minimum diameter of 5 mm and 25 mm embedment.

Design according to CEN/TR 17079 with loads limited to 2, 3 kN for at least 3 or 4 anchors.

Qualification and design provisions limited to static loading.

Focus on single point fastening in the following slides of this presentation.

TWO SEISMIC CATEGORIES C1 AND C2 ARE DISTINGUISHED BASED ON SEISMICITY LEVEL AND IMPORTANCE CLASS

Table C.1 — Recommended seismic performance categories for fasteners

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 seismic performance category required			
Low[b]	$0{,}05\ g < a_g \cdot S \leq 0{,}1\ g$	C1	C1[d] or C2[e]		C2
> low	$a_g \cdot S > 0{,}1\ g$	C1	C2		

[a] The values defining the seismicity levels are subject to a National Annex. The recommended values are given here.
[b] Definition according to EN 1998-1:2004, 3.2.1.
[c] a_g = design ground acceleration on type A ground (see EN 1998-1:2004, 3.2.1),
S = soil factor (see EN 1998-1:2004, 3.2.2).
[d] C1 for fixing non-structural elements to structures (Type 'B' connections).
[e] C2 for fixing structural elements to structures (Type 'A' connections).

National Implementation

Seismicity level:

Eurocode 8 "Design of structures for earthquake resistance" (2004) uses seismicity level to define level of design procedure.

- Very low: EC 8 provisions need not be observed
- Low: reduced or simplified seismic design procedures for certain types or categories of structures may be used.

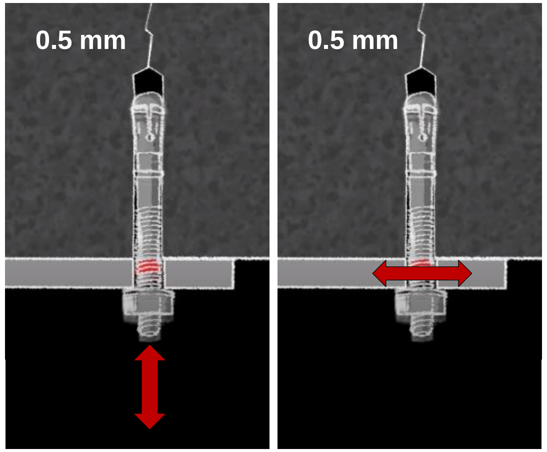
Importance Class:

Accounts for consequences of collapse for human life, importance for public safety and civil protection in immediate post-earthquake period, an social and economic consequences of collapse.

THE SEISMIC CATEGORIES C1 AND C2 RECOGNIZED BY EN 1992-4 ARE ASSOCIATED TO DIFFERENT ASSESSMENTS

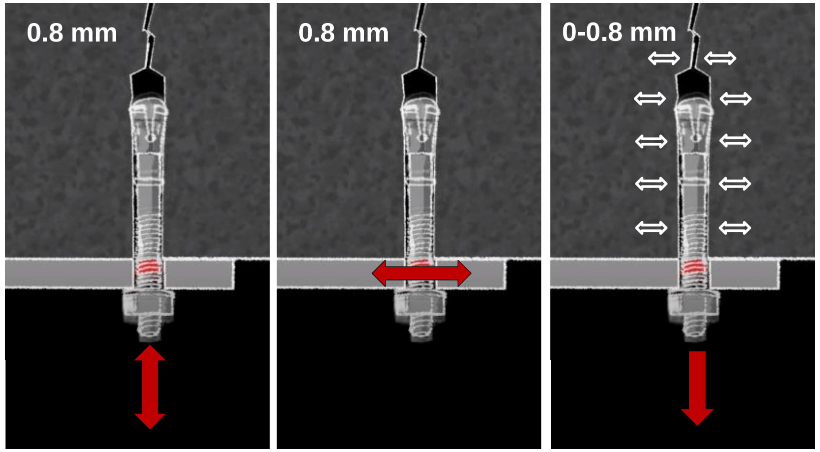
Anchor assessment for seismic category C1 as per EOTA EADs 499 and 232

Test	Description	Concrete	Δw [mm]
C1.1	Pulsating tension load	C20/25	0,5
C1.2	Alternating shear load	C20/25	0,5

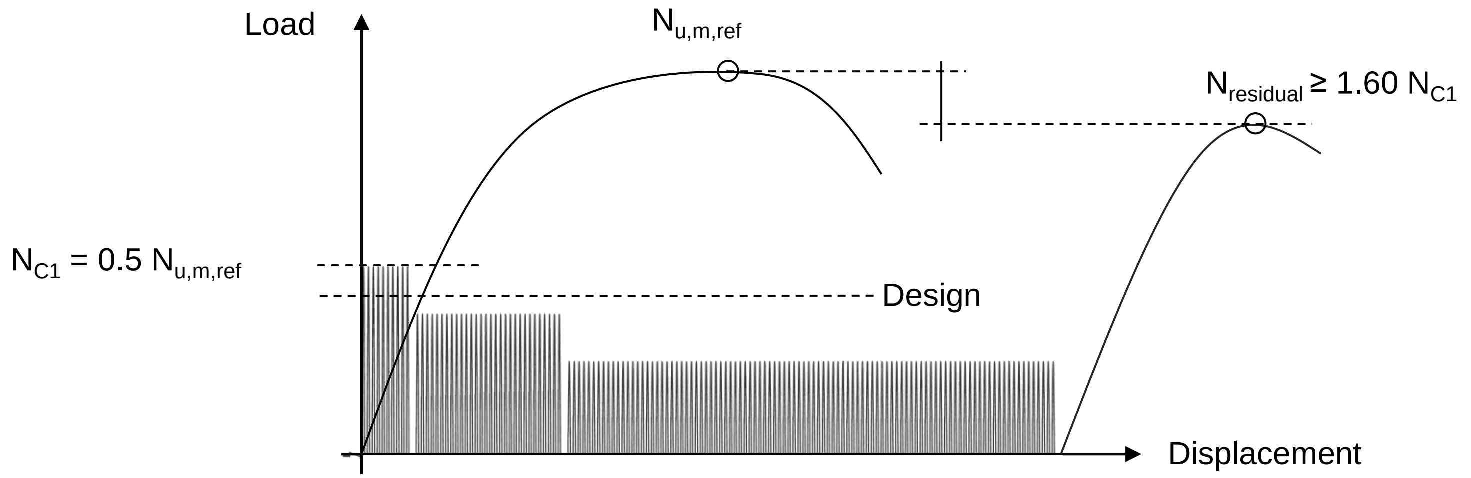


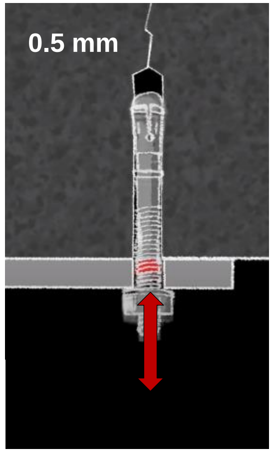
Anchor assessment for seismic category C2 as per EOTA EADs 499 and 232

Test	Description	Concrete	Δw [mm]
C2.1a	Reference test - tension	C20/25	0,8
C2.1b	Reference test - tension	C50/60	0,8
C2.2	Reference test - shear	C20/25	0,8
C2.3	Pulsating tension load	C20/25	0,5 (≤ $0{,}5 \cdot N/N_{max}$) 0,8 (> $0{,}5 \cdot N/N_{max}$)
C2.4	Alternating shear load	C20/25	0,8
C2.5	Cyclic crack opening with constant tension load	C20/25	0,1 – 0,8



SEISMIC PERFORMANCE CATEGORY C1 – PULSATING TENSION LOAD TEST (SERIES C1.1)



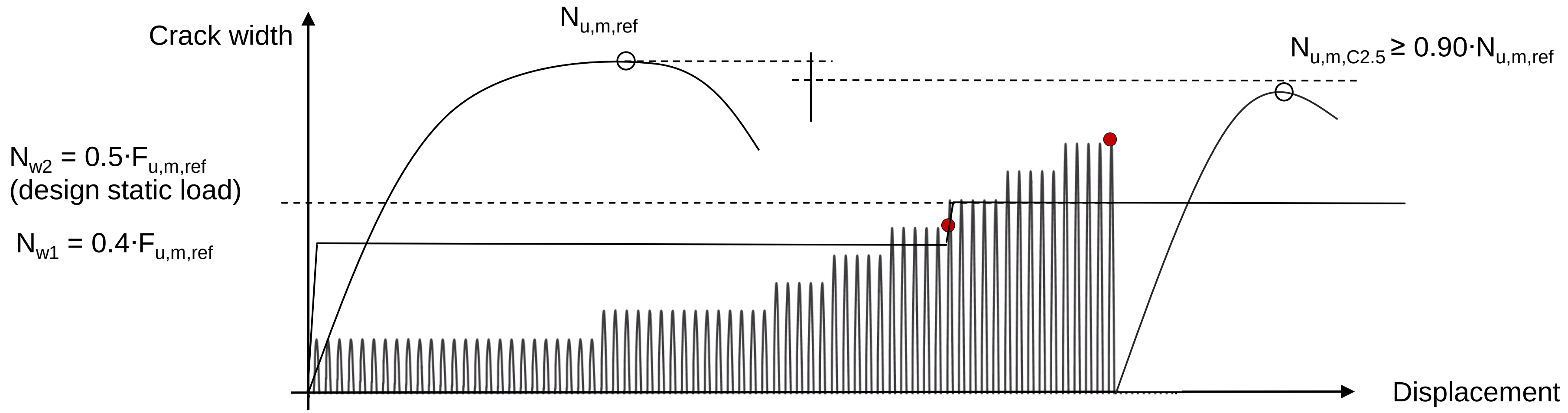


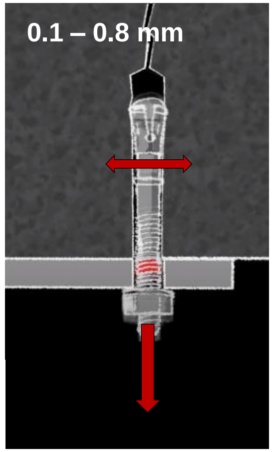
Pulsating tension load

<u>Philosophy:</u>

- **Force based loading protocol** of 140 cycles primarily reflecting by inertia-induced cyclic tension (and shear) loads acting on anchors in the structural load path as well as those connecting non-structural elements to the primary structure *(Silva, 2001)*
- **Maximum applied load** to simulate earthquake load cycling at level (slightly) greater than (max. anticipated) design load
- Demonstrate **residual anchor strength** to be statistically equivalent to reference capacity (taking into account the increased crack width in the seismic test)
- Use the **reference strength**, which is adjusted based on the reliably test results

SEISMIC PERFORMANCE CATEGORY C2 – TENSION UNDER CRACK WIDTH CYCLING (SERIES C2.5)





Constant tension loading

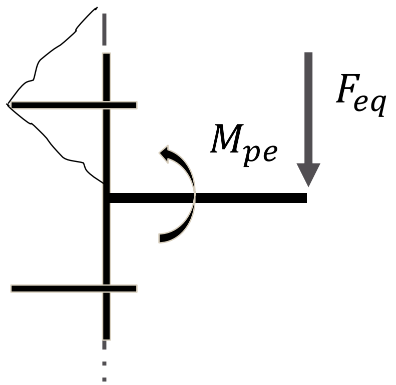
● Evaluation of displacement

Philosophy:

- **Loading protocol** derived from nonlinear numerical simulations on benchmark buildings and selected earthquake spectra considering rigidly attached oscillators representing nonstructural components and systems (NCS), *(Wood & Hutchinson, 2013)*
- **Maximum applied load** to simulate earthquake load cycling at level of design static load
- Demonstrate **residual anchor strength** to be statistically equivalent to reference capacity (taking into account the increased crack width in the seismic test)
- Use the **reference strength**, which is adjusted based on the reliably test results
- Additional **assessment of displacement** behavior at DLS (0.5 mm) and ULS

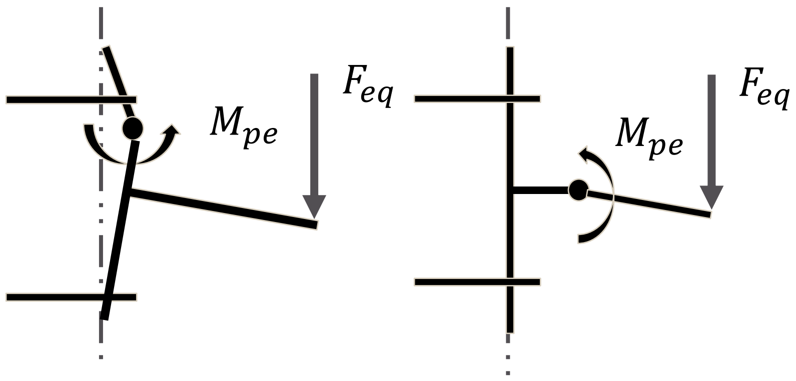
DIFFERENT DESIGN STRATEGIES CAN BE CHOSEN TO RESIST SEISMIC ACTIONS: ELASTIC DESIGN IS COMMON PRACTICE FOR NON-STRUCTURAL ELEMENTS

Elastic design (cat. C1 & C2)



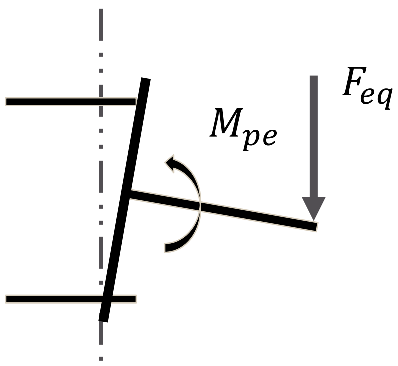
- (+) Easy design following the principles applicable for static loading
- (−) High seismic actions considering the behavior factor q = 1.0

Capacity design (cat. C1 & C2)



- (+) Ductile failure achieved by yielding of the attached element
- (−) Need to over-design anchors to ensure high resistance than attached member

Ductile design (cat. C2)



- (+) Ductile failure achieved by yielding of the anchor. No damage to attached element
- (−) Need for anchor capable of ductile failure (i.e., steel yielding as decisive failure mode)

SEISMIC FORCES ACTING ON FASTENERS AS PER EN 1998-1 AND EN 1992-4 **(NON-STRUCTURAL ELEMENTS)**

Horizontal action

$$F_{ha} = (S_{ha} \cdot W_a \cdot \gamma_a)/q_a$$

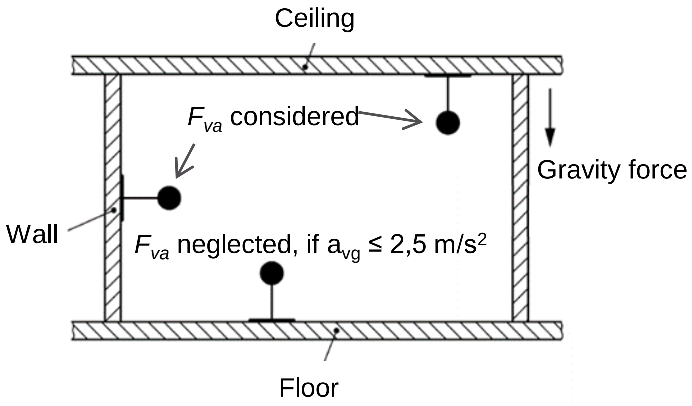
$$S_{ha} = \alpha_h \cdot S \cdot \left[\frac{3\left(1+\frac{z}{H}\right)}{1+\left(1-\frac{T_a}{T_1}\right)^2} - 0{,}5 \right]$$

$$\geq \alpha_h \cdot S$$

Vertical action

$$F_{va} = (S_{va} \cdot W_a \cdot \gamma_a)/q_a$$

$$S_{va} = \alpha_v \cdot A_a$$



Basic concept from EN 1998-1 and simplified approach to calculate actions on non-structural elements according to EN 1992-4, when fundamental vibration period T_a of the non-structural element is not known.

$$A_a = \frac{3}{1+\left(1-\frac{T_a}{T_1}\right)^2}$$

- F_a seismic force acting at the centre of mass on a non-structural element (appendage) in the most unfavourable direction
- W_a **weight** of the non-structural element
- S_a seismic coefficient applicable to non-structural elements
- γ_a **importance factor** of the non-structural element
- q_a **behaviour factor** for non-structural elements
- α ratio of the design **ground acceleration** on type A ground
- S **soil factor**
- T_a fundamental period of vibration of the non-structural element
- T_1 fundamental period of vibration of the building in the relevant direction
- z **height of the non-structural element** above the level of application of the seismic action
- H building height

Table C.2 — Values of q_a and A_a for non-structural elements

	Type of non-structural element	q_a	A_a
1	Cantilevering parapets or ornamentations	1,0	3,0
2	Signs and billboards		3,0
3	Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height		3,0
4	Hazardous material storage, hazardous fluid piping		3,0
5	Exterior and interior walls	2,0	1,5
6	Partitions and facades		1,5
7	Chimneys, masts and tanks on legs acting as unbraced cantilevers along less than one half of their total height, or braced or guyed to the structure at or above their centre of mass		1,5
8	Elevators		1,5
9	Computer access floors, electrical and communication equipment		3,0
10	Conveyors		3,0
11	Anchorage elements for permanent cabinets and book stacks supported by the floor		1,5
12	Anchorage elements for false (suspended) ceilings and light fixtures		1,5
13	High pressure piping, fire suppression piping		3,0
14	Fluid piping for non-hazardous materials		3,0
15	Computer, communication and storage racks		3,0

THE NEXT GENERATION OF EUROCODES WILL BE BRING MODIFICATIONS

Table G.1 – Seismic performance classes of post-installed fasteners used in design situations

Seismic action class	Connection	Design option	Ductility class of main structure	
			DC1	DC2 & DC3
Low	Type A and Type B	OP1 or OP2	SPR1	SPR2
		OP3	SPR2	SPR2
Moderate or high	Type A	OP2	SPR2	SPR2
		OP3	SPR2	SPR2
	Type B	OP1	SPR1	-
		OP2	SPR1	SPR2
		OP3	SPR2	SPR2

Type A: connections between primary and/or secondary seismic members;

Type B: connections of ancillary elements and of equipment to primary and/or secondary seismic members.

OP1: design assuming elastic behaviour of the structure-and fastening;

OP2: design with action effects in the fastenings allowing the connected members to exploit their maximum strength according to capacity design rules given in G.3.3(5) and (6);

OP3: design with requirements on the ductility of the fasteners.

Key differences between current and next. Gen Eurocodes:

- Seismic design of anchors will be moved from EN 1992-4 to EN 1998-1-1
- Seismic category classes renamed into SPR1 and SPR2. However, same meaning of C1 and C2, thanks to link to relevant EADs.
- Design options a1, a2 and b are renamed into OP2, OP1 and OP3
- Seismic categories are associated to seismic action class and ductility class of the structure for which the design is carried out (not anymore to the building importance class!).
- Link between “connection type” (structural/non-structural) and “design option” is established

SUMMARY AND CONCLUSIONS

- The **failure of non-structural elements during an earthquake pose significant risks**, i.e.,
    - Risk to human life
    - Significant economical loss
    - Interruption of operation of potentially strategic buildings and infrastructures (e.g., hospitals)

  Therefore, the seismic design of the connections of these elements is of primary importance

- The **European code framework does not offer solutions for seismic qualification and design of "redundant fastenings"** that are commonly used for fix lightweight elements such as suspended ceilings. Therefore, anchors allowed for single point fastenings must be used for the fixing of all non-structural components.

- **EN 1992-4 includes comprehensive seismic design provisions for single point fastenings considering two different categories C1 and C2**. The choice between these categories is ruled in the national annexes of the member states. Actions can be derived following the provisions of EN 1998-1

- **Both seismic category C1 and C2 assessment provisions of EOTA were derived with focus on non-structural elements**. However, the differences are significant and understanding them can help to choose the right product and seismic category for a specific application (e.g., crack widths and displacements checks).

THANKS

SEISMIC DESIGN OF ANCHORS IS REQUIRED FOR STRUCTURAL AND NON-STRUCTURAL CONNECTIONS

Structural connections




Non-structural connections




Fastenings in non-structural connections may require to resist forces in a wide range (between < 1kN up to >>10 kN). Displacement requirements may also need to be fulfilled.