X EDIZIONE SEISMIC ACADEMY

Think smart, build safe

13 giugno 2023

Progettazione sismica di elementi non strutturali: evoluzione normativa e avanzamenti della ricerca

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Contents

- Seismic design issues for nonstructural building elements
- Nonstructural building elements in the current Eurocode 8
- The new generation of Eurocode 8
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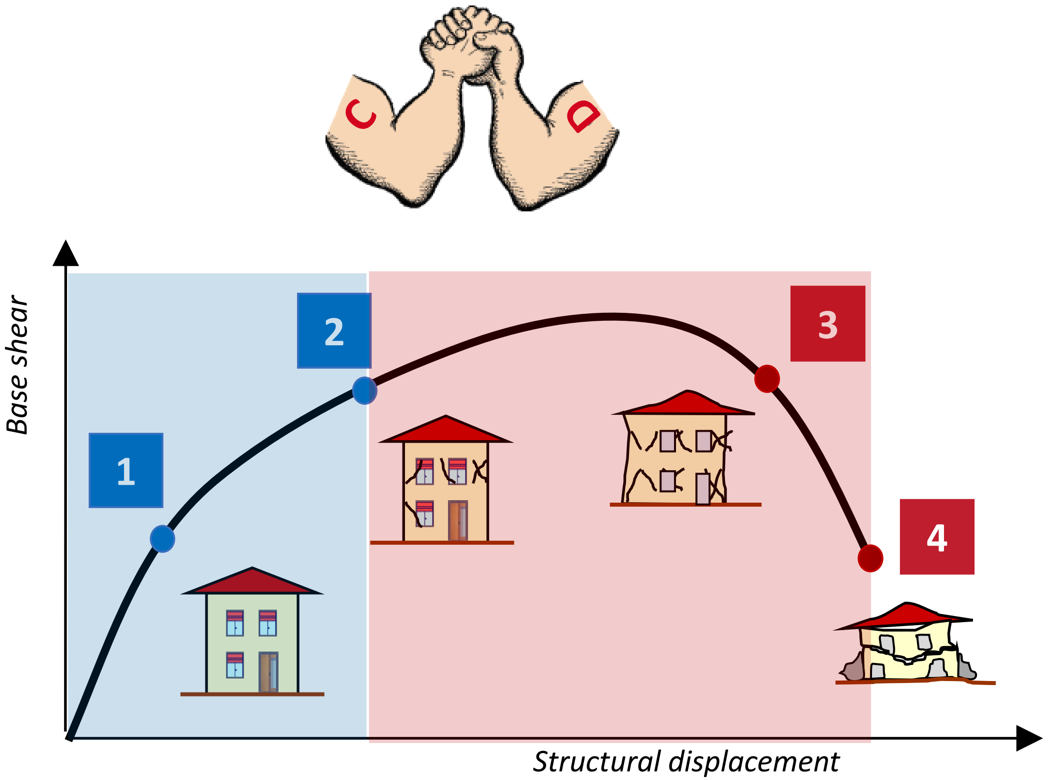
General approach



Serviceability Limit States (SLS)

1. Fully operational:

Only minor structural or non-structural damage occurred. The building retains its original stiffness and strength. Non-structural components operate and the building is available for continuous service. The risk of life threatening injury is negligible.

2. Damage limitation:

Only minor structural damage occurred. The building structure retains nearly its original stiffness and strength. Non-structural components are secured and most of them would function. The risk of life threatening injury is very low. The service interruption is less than 3 days.

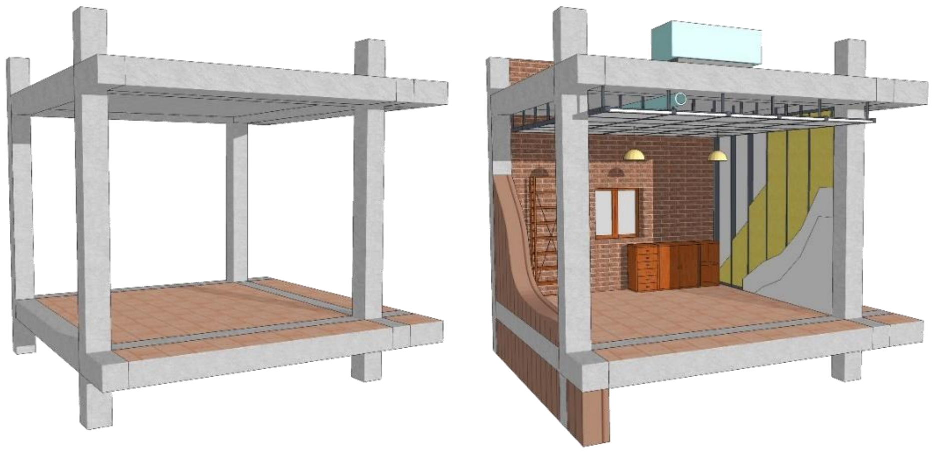
Ultimate Limit States (ULS)

3. Life Safety:

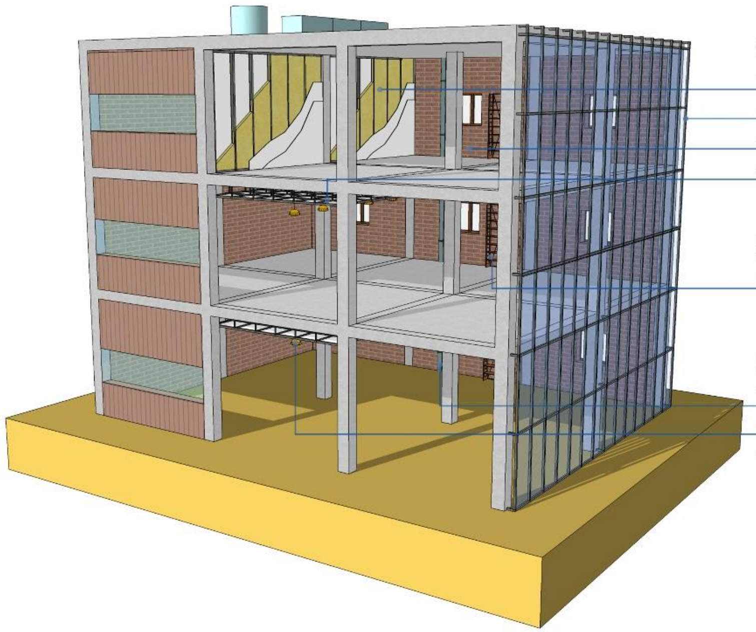
Significant structural and non-structural damage occurred. The lateral strength has still a margin against collapse. Non-structural components are secure, but cannot operate. The building may not be safe for occupancy until repaired. The risk of life threatening injury is low. The service interruption is less than 3 months.

4. Near Collapse:

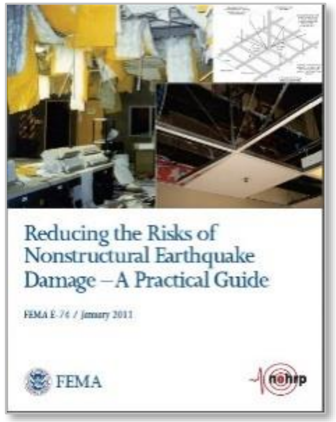
Substantial damage occurred. The building has lost most of its original stiffness and strength, having a very little margin against collapse. Non-structural components may become dislodged and present a falling hazard. In many cases the repair is not practical.



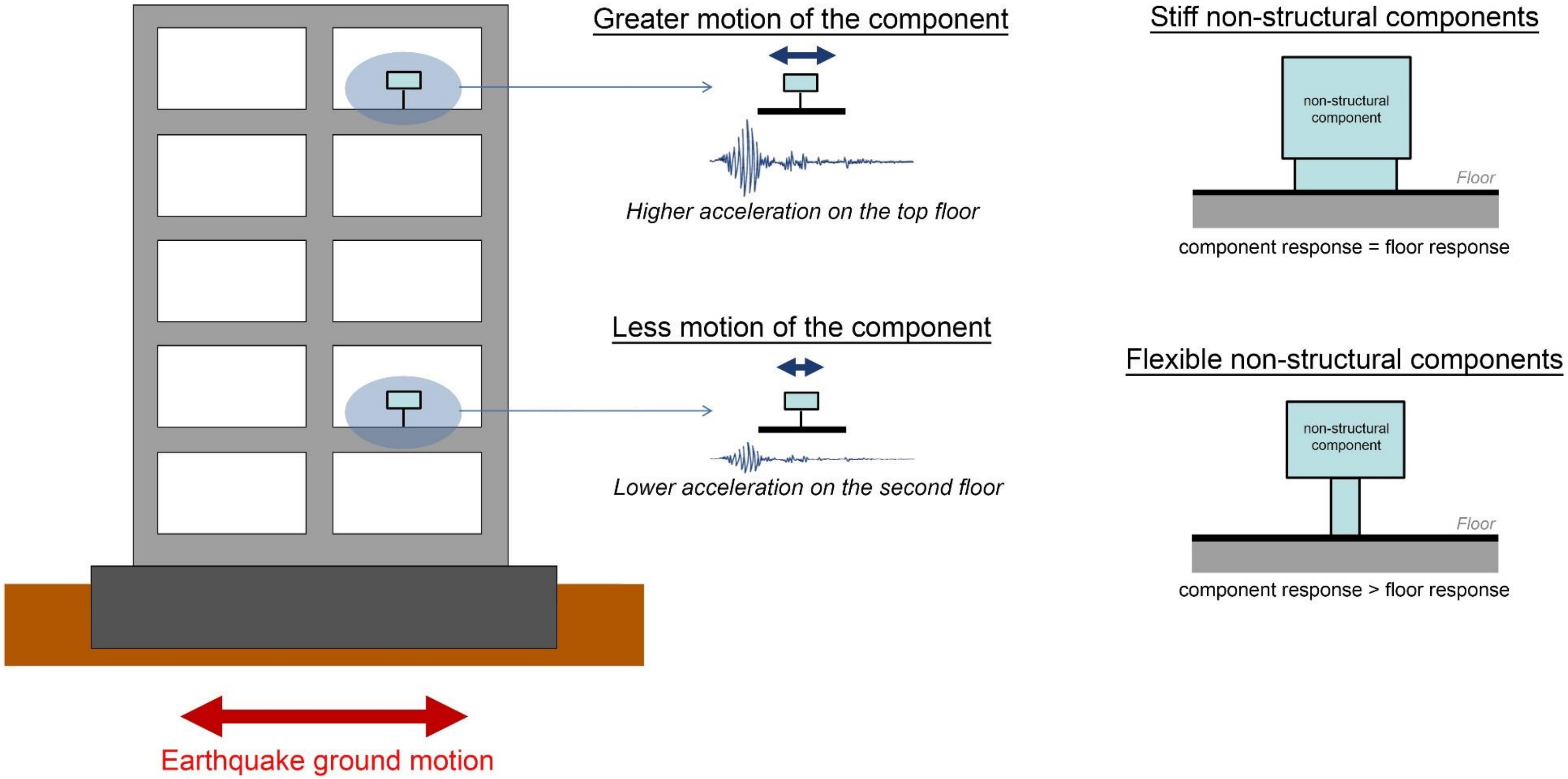
Non-structural components are defined as those systems and elements housed in or attached to a building, which are not part of the main load-bearing structural system (*Villaverde, 1997*)



They are commonly classified according to the typological functions performed in the building (FEMA E-74, 2011)

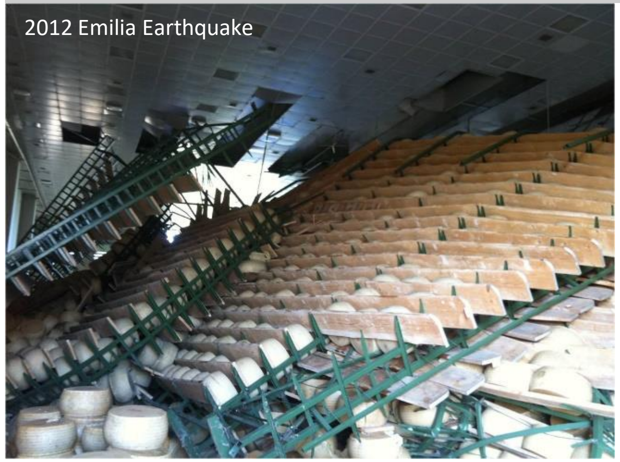


The seismic response of non-structural building components during an earthquake depends mainly on the component location within the building structure and on the component's dynamic characteristics

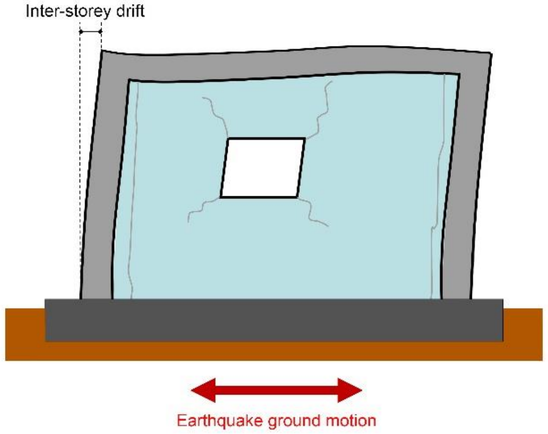


Main causes of seismic damage

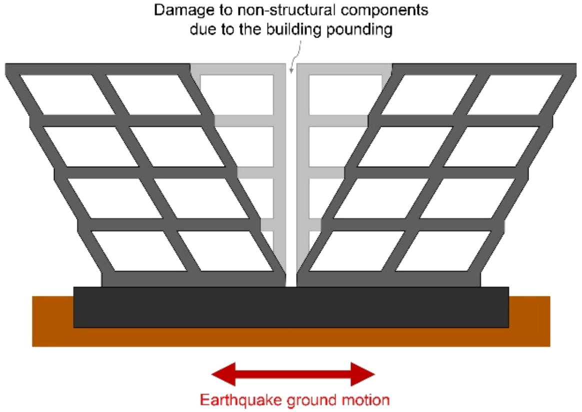
Effects of the inertial forces



Effects of the building deformation



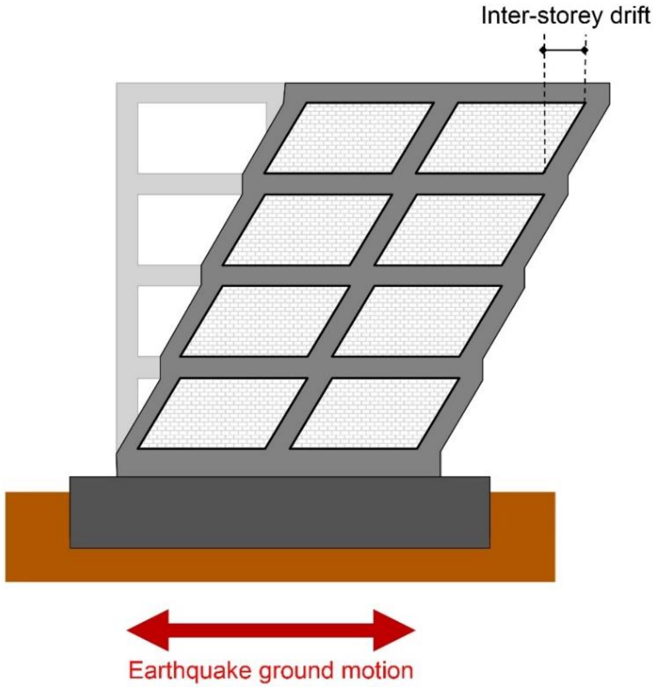
Effects of the building pounding

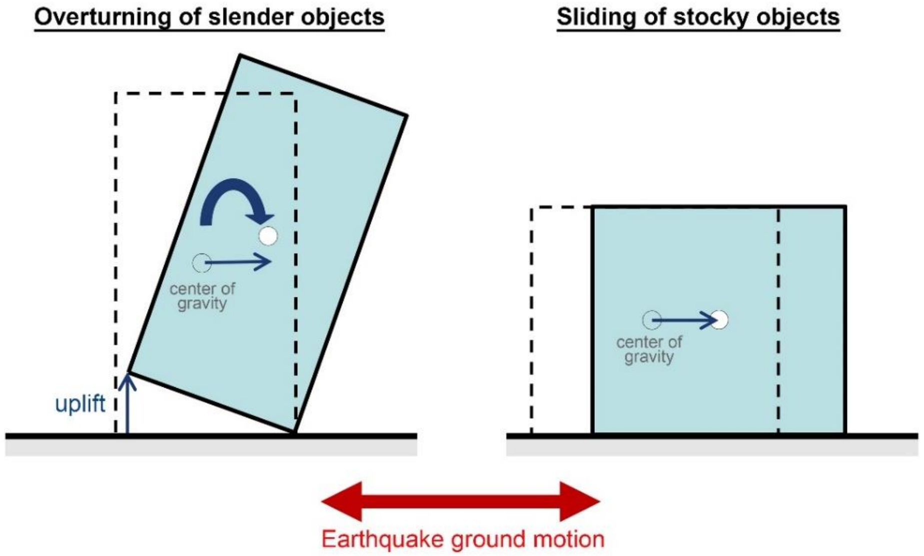


Effects of the interaction

The seismic response of non-structural building components is affected mainly by their sensitivity to several response parameters of the structure (ASCE/SEI 41-13, 2013) and they are distinguished in:

- deformation-sensitive components
- acceleration-sensitive components
- deformation-and-acceleration-sensitive components





The discussion deals with the seismic design issues and procedures for non-structural lightweight steel drywall building components, i.e. gypsum board walls and suspended gypsum board ceilings

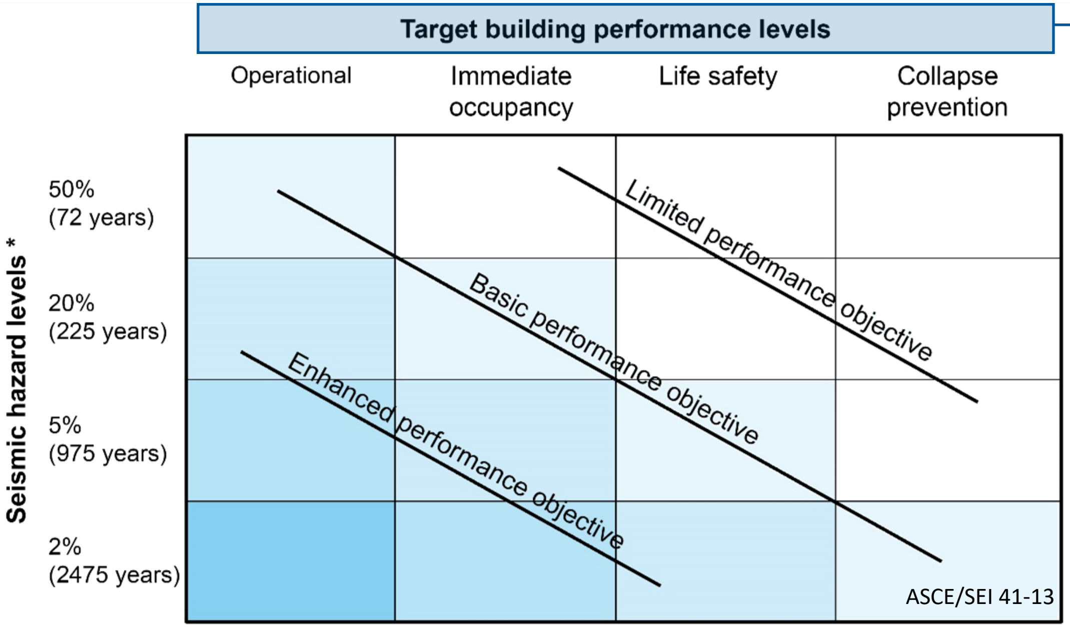
Architectural components	Acceleration-sensitive	Deformation-sensitive
Walls		
Heavy	S	P
Light	S	P
Ceilings		
Directly applied to the building structure	P	
Suspended gypsum board ceilings	P	
Suspended acoustic lay-in tile ceilings	S	P

P: Primary response; S: secondary response

Target Non-structural Performance Levels

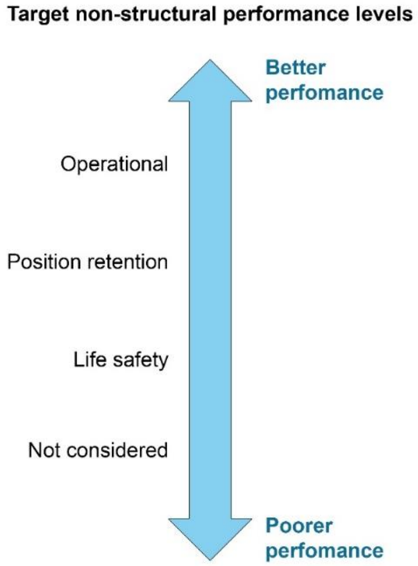
The most advanced building codes based on the “Performance-Based Design” philosophy currently recognize the importance of a rational seismic design of non-structural components. The main reason is related to the vulnerability and the higher seismic fragility of these systems.

ASCE/SEI 41-13 *“Seismic Evaluation and Retrofit of Existing Buildings”*
ASCE/SEI 7-10 *“Minimum Design Loads for Buildings and Other Structures”*



* *Ground motions are referred to the probability of exceedance (%) in 50 years and the corresponding mean return period (years)*

Building performance is a combination of the performance of both structural and non-structural components



Component group	Target Non-structural Performance Levels		
	Life Safety	**Position Retention**	**Operational**
Partitions (plaster and gypsum)	Distributed damage; some severe cracking, crushing and racking in some areas	Cracking at openings. Minor cracking and racking throughout	Minor cracking
Ceilings	Extensive damage. Plaster ceilings cracked and spalled, but did not drop as a unit. Tiles in grid ceilings dislodged and falling; grids distorted and pulled apart. Potential impact on immediate egress. Potential damage to adjacent partitions and suspended equipment	Limited damage. Plaster ceilings cracked and spalled, but did not drop as a unit. Suspended ceiling grids largely undamaged, though individual tiles falling	Generally negligible damage with no impact on reoccupancy or functionality

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Nonstructural building elements in the current Eurocode 8

EN 1998-1

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EN 1998-1

December 2004

ICS 91.120.25

Supersedes ENV 1998-1-1:1994, ENV 1998-1-2:1994, ENV 1998-1-3:1995

English version

Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings

Eurocode 8: Calcul des structures pour leur résistance aux séismes - Partie 1: Règles générales, actions sismiques et règles pour les bâtiments

Eurocode 8: Auslegung von Bauwerken gegen Erdbeben - Teil 1: Grundlagen, Erdbebeneinwirkungen und Regeln für Hochbauten

This European Standard was approved by CEN on 23 April 2004.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CEN member.

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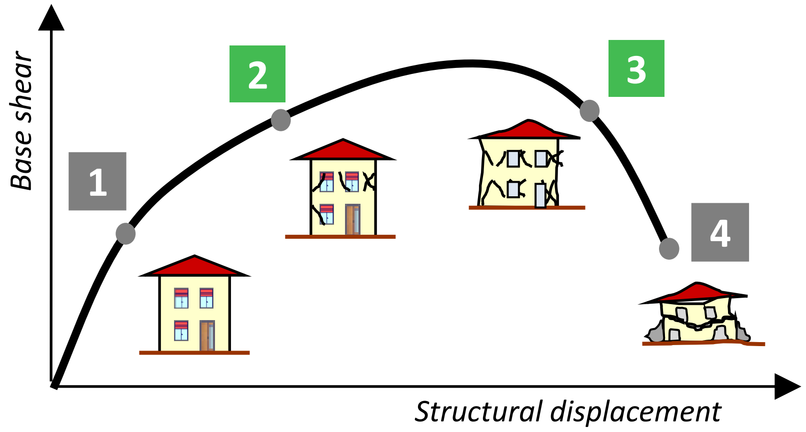
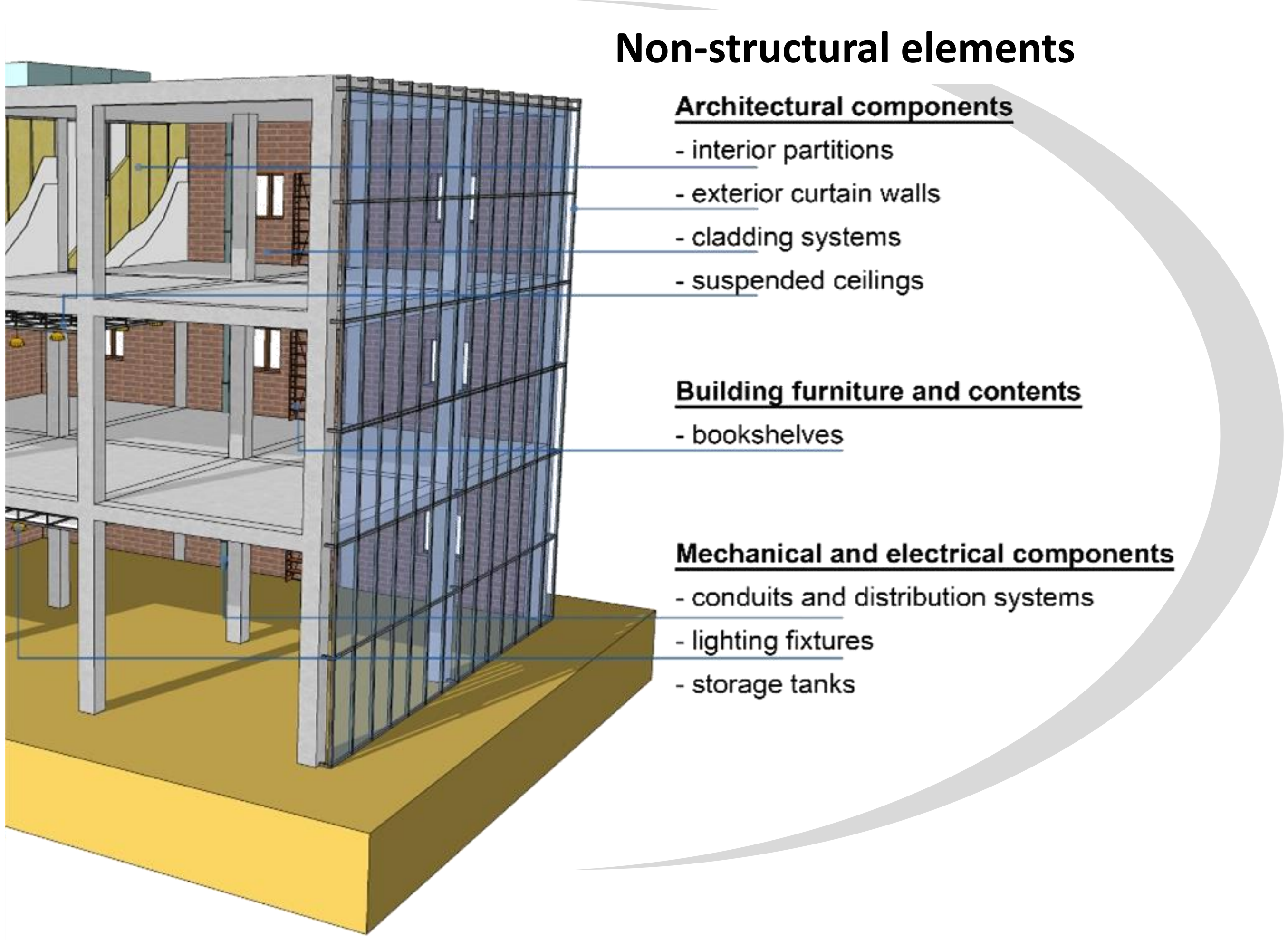


1. Fully Operational
2. **Damage Limitation**
3. **Life Safety**
4. Near Collapse

Nonstructural building elements in the current Eurocode 8 *General definitions and prescriptions*

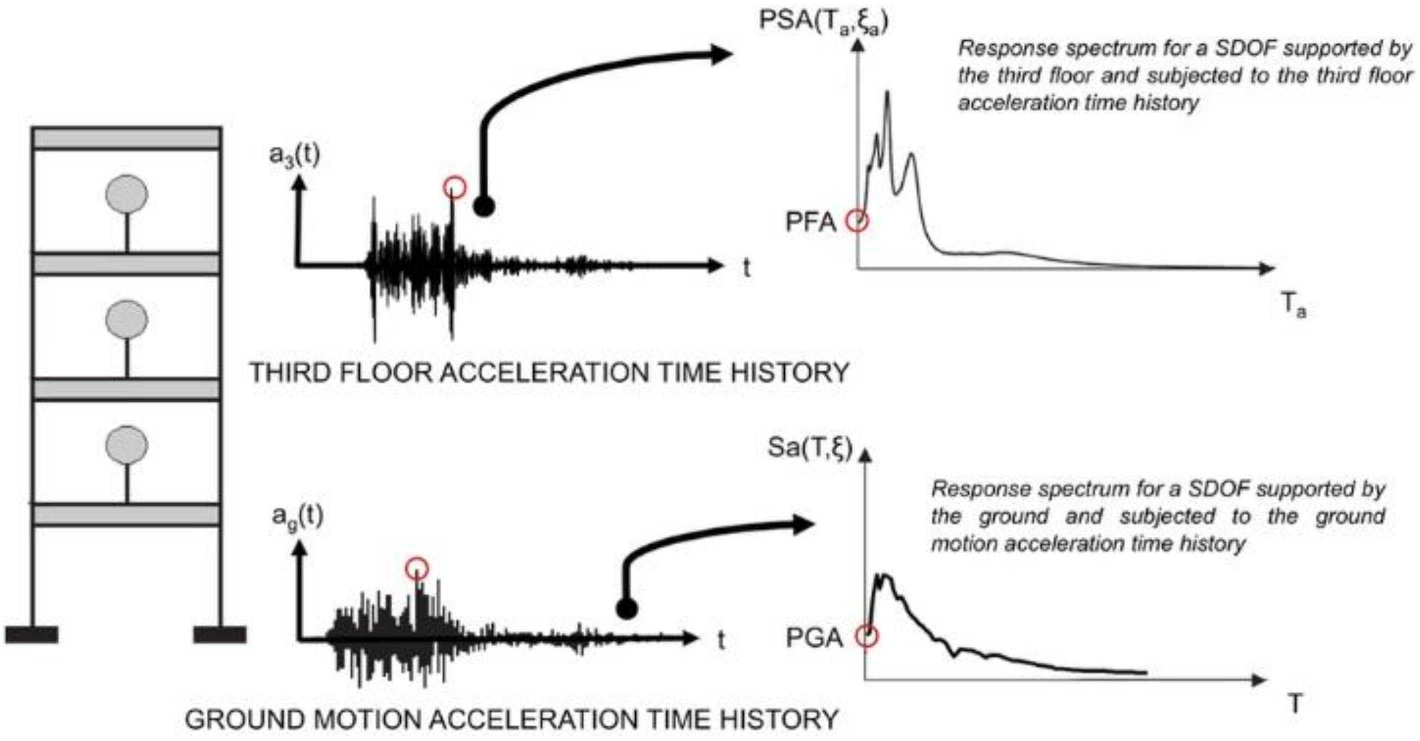


System and component which, whether due to **lack of strength** or to the way it is connected to the structure, is not considered in the seismic design as load carrying element

Non-structural elements of buildings that might, in case of failure**, cause risks to persons** or **affect the main structure** or **services of critical facilities**

Shall be verified together with their supports to resist the design seismic action

Floor response spectra approach



Di Domenico, M, Ricci, P, Verderame, GM. Floor spectra for bare and infilled reinforced concrete frames designed according to Eurocodes. *Earthquake Engng Struct Dyn*. 2021; 50: 3577– 3601. https://doi.org/10.1002/eqe.3523

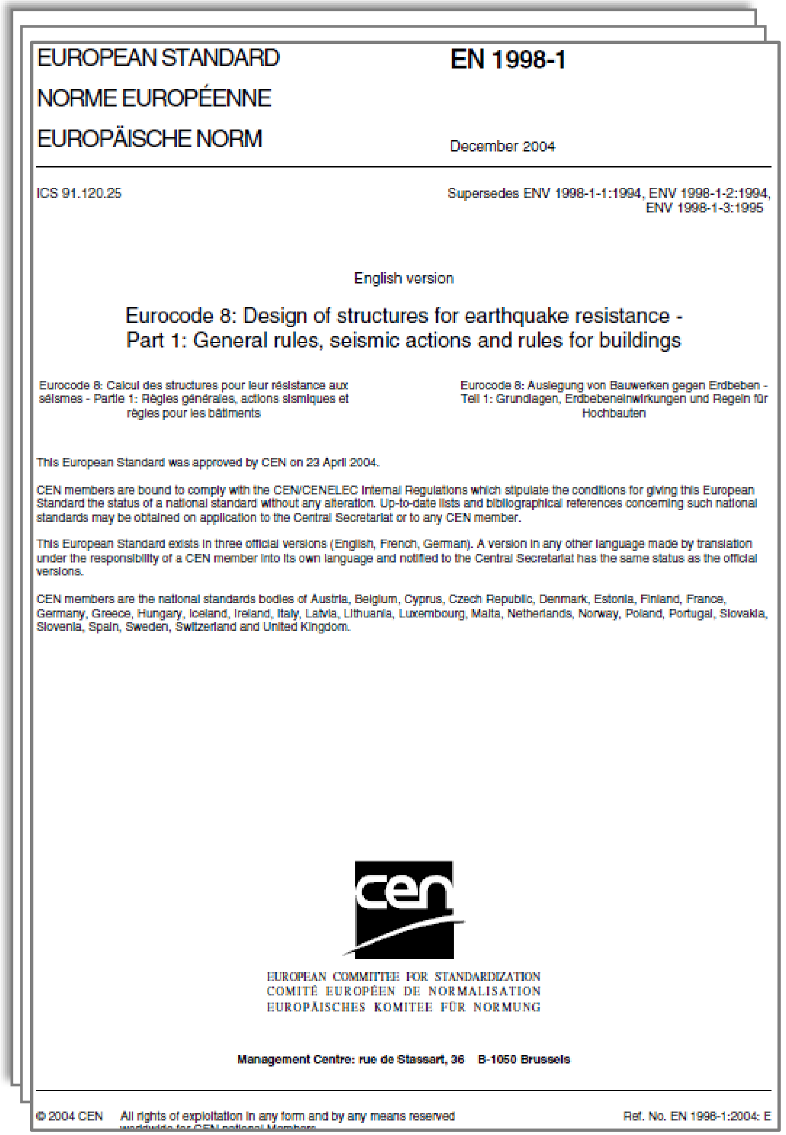
The primary structure is subjected at ground to a certain acceleration time-history with a certain Peak Ground Acceleration (PGA).

The structural system consequently will experience a certain pseudo-spectral acceleration.

A certain floor of the structure will experience a certain acceleration time-history with a certain Peak Floor Acceleration (PFA).

The maximum pseudo-spectral acceleration (PSA) acting on the SDOF (non structural component) can be calculated through the pseudoacceleration response spectrum of the acceleration time-history of the supporting floor.

Nonstructural building elements in the current Eurocode 8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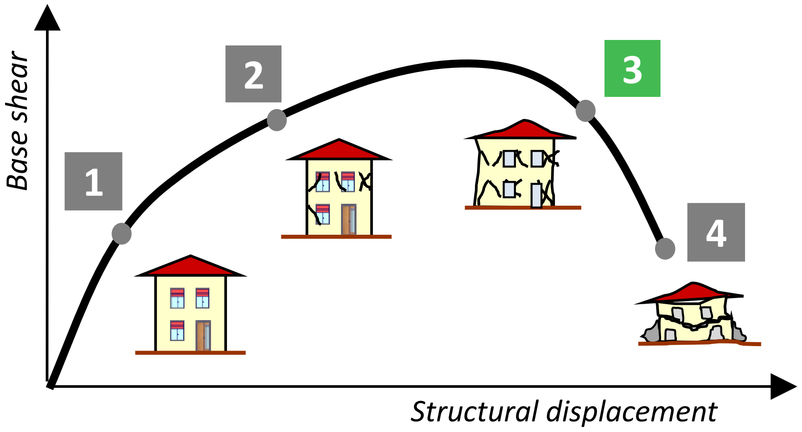

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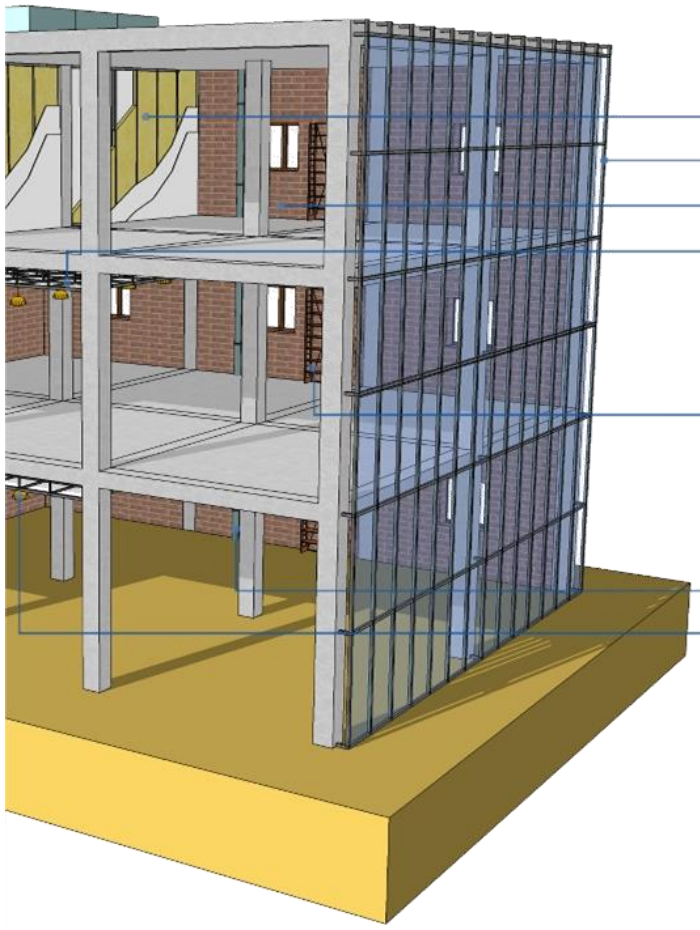
General definitions and prescriptions



Non-structural elements

Architectural components
- interior partitions
- exterior curtain walls
- cladding systems
- suspended ceilings

Building furniture and contents
- bookshelves

Mechanical and electrical components
- conduits and distribution systems
- lighting fixtures
- storage tanks

Non-structural elements with great importance or particularly dangerous nature

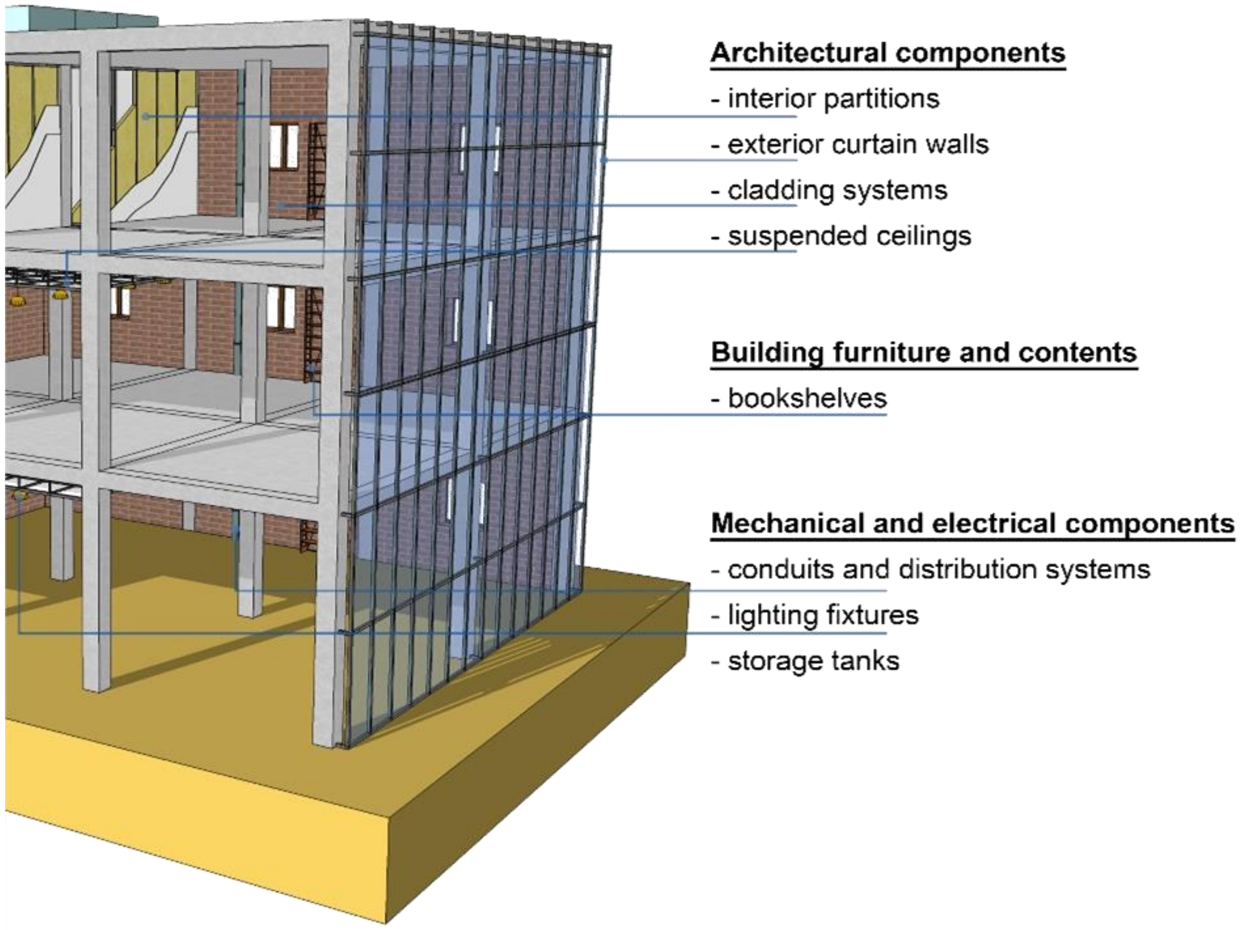
- Seismic analysis based on a realistic model of the relevant structures
- floor acceleration spectrum

Non-structural elements without great importance or not particularly dangerous nature

- Simplified procedure

Additional measures for masonry infilled frames in Section 4.3.6

Nonstructural building elements in the current Eurocode 8



Level of performances

LS of the structural system

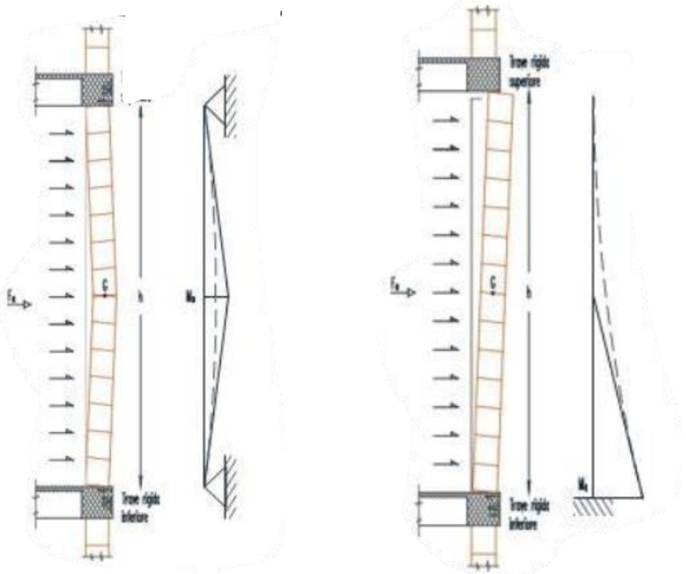
Demand:

axceleration (Fa)

Safety verifications

The non-structural elements, as well as their connections and attachments or anchorages, shall be verified for the seismic design situation

The effects of the seismic action may be determined by applying to the non-structural element a horizontal force Fa, acting in the most unfavourable direction.



Verification of the nonstructural building elements - Section 4.3.5.2 (Non-structural element)

Horizontal design seismic force

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

acting maximum acceleration

$$S_a = \alpha \cdot S \cdot \left[\frac{3 \cdot (1 + z/H)}{1 + (1 - T_a/T_1)^2} - 0.5\right] \geq \alpha \cdot S$$

The term represents the design ground acceleration

The term represents the amplification of earthquake shaking as a function of the building height

T_a / T_1 represents the flexibility or stiffness of the non-structural component

- W_a = weight of the component
- γ_a = importance factor of the component (1.0 ÷ 1.5)
- q_a = behaviour factor of the element (1.0 ÷ ***2.0***)
- S_a = seismic coefficient applicable to non-structural component
- α = ratio of the design ground acceleration on type A ground, ag, to the acceleration of gravity g
- S = soil factor
- Z = height of the non-structural component above the level of application of the seismic action
- H = building height measured from the foundation or from the top of a rigid basement
- T_a = fundamental vibration period of the non-structural component
- T_1 = fundamental vibration period of the building in the relevant direction

Fa is the horizontal seismic force, acting at the centre of mass of the non-structural element in the most unfavourable direction

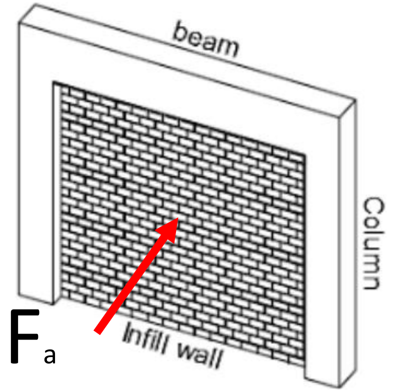


Table 4.4: Values of q_a for non-structural elements

Type of non-structural element	q_a
Cantilevering parapets or ornamentations Signs and billboards Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height	1,0
Exterior and interior walls Partitions and facades 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 Anchorage elements for permanent cabinets and book stacks supported by the floor Anchorage elements for false (suspended) ceilings and light fixtures	2,0

Nonstructural building elements in the current Eurocode 8

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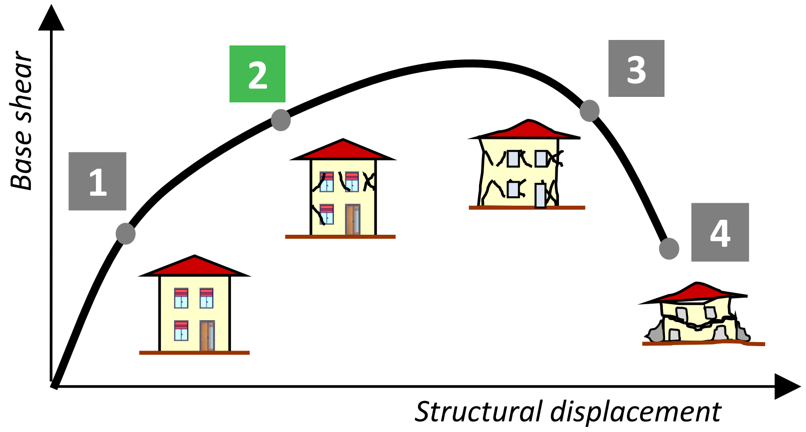
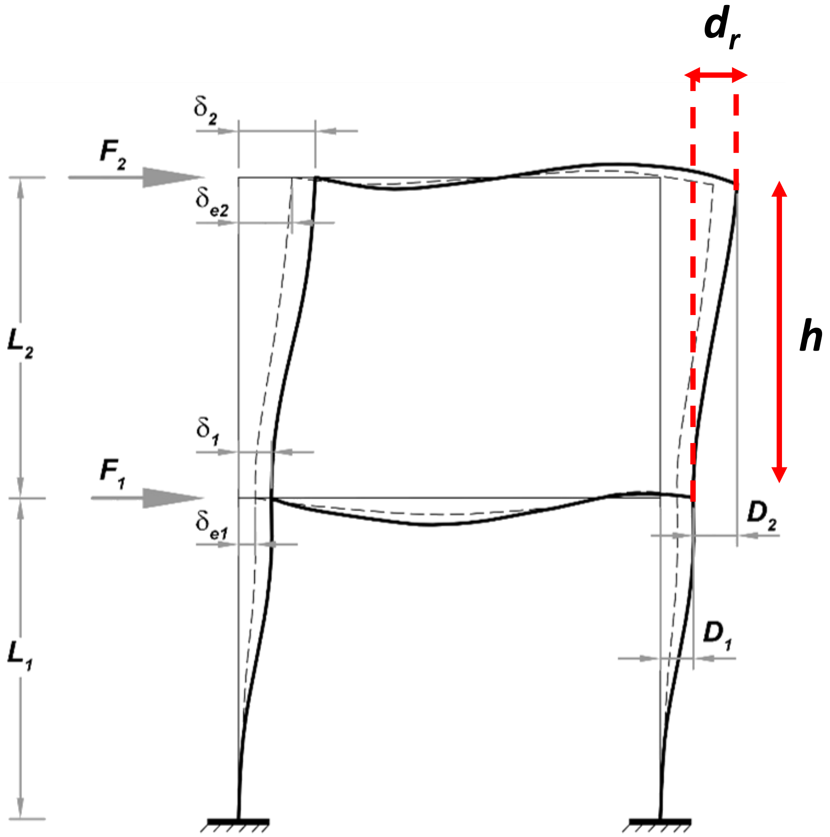


1. Fully Operational
2. **Damage Limitation**
3. Life Safety
4. Near Collapse

Limitation of interstorey drift - Section 4.4.3.2 (Damage limitation)

Horizontal design seismic force

$$\frac{d_r \cdot \nu}{h} \le \begin{cases} 0.5\% & \text{for buildings having non-structural components made of brittle materials and attached to the structure} \\ 0.75\% & \text{for buildings having ductile non-structural components} \\ 1.0\% & \text{for buildings having ductile non-structural components fixed in a way so as not to interfere with structural deformations} \end{cases}$$



- d_r = design inter-storey drift, that is evaluated as the difference of the average lateral displacements at the storey top and bottom, which are obtained by a linear analysis of the structural system based on the design response spectrum (i.e. for a rare seismic event with 475-year return period).
- ν = reduction factor takes into account the lower return period of the seismic action associated with the damage limit state (0.4 ÷ 0.5 depending on the importance class of building)
- h = storey height

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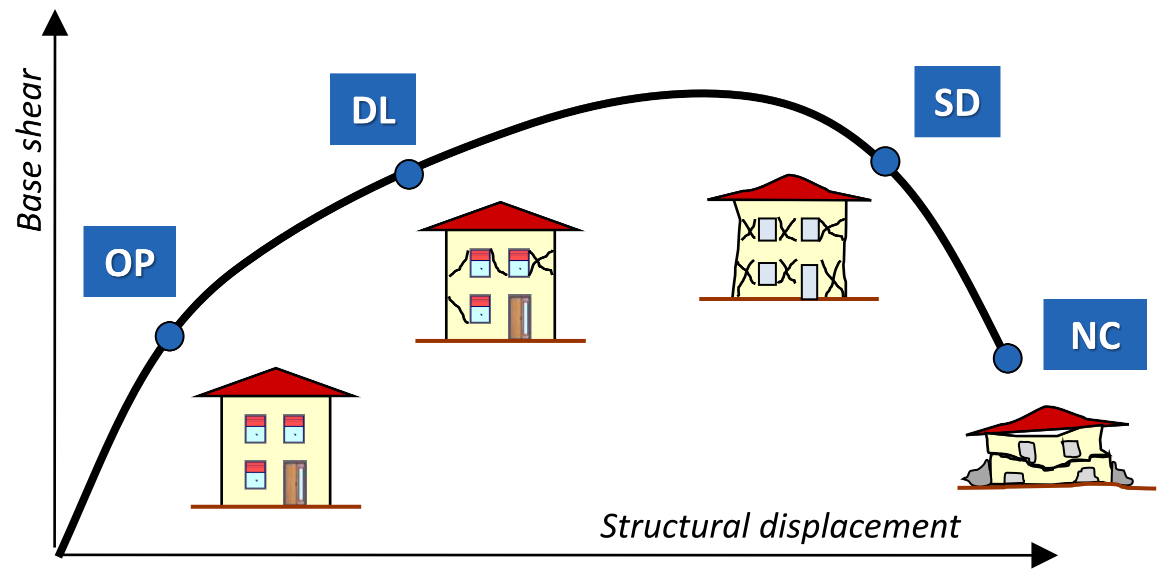
The structure of the new Eurocode 8

The structure and organization of new Eurocode 8 is significantly changed as respect to the current EN1998 (2004) in order to identify a general part common to all other parts for avoiding repetition

EN 1998 1ST GENERATION
1 General rules and buildings
2 Bridges
3 Existing buildings
4 Silos, tanks and pipelines
5 Foundations and retaining structures
6 Tower, masts and chimneys

EN 1998 2ND GENERATION
1-1 General rules
1-2 Buildings
2 Bridges
3 Existing buildings and bridges
4 Silos, tanks, pipelines, towers, masts and chimneys
5 Foundation, retaining structures and Geotechnical aspects

ULS in current EC8-1



OP - Fully operational Continuous service. Negligible structural and nonstructural damage.

DL - Damage Limitation Most operations and functions can resume immediately. Structure safe for occupancy. Essential operations protected, non-essential operations disrupted. Repair required to restore some non-essential services. Damage is light.

SD - Significant Damage Damage is moderate, but structure remains stable. Selected building systems, features, or contents may be protected from damage. Life safety is generally protected. Building may be evacuated following earthquake. Repair possible, but may be economically impractical.

NC - Near Collapse Damage severe, but structural collapse prevented. Nonstructural elements may fall. Repair generally not possible pr*EN 1998-1-1: Eurocode 8 — Design of structures for earthquake resistance —Part 1-1: General rules and seismic action*

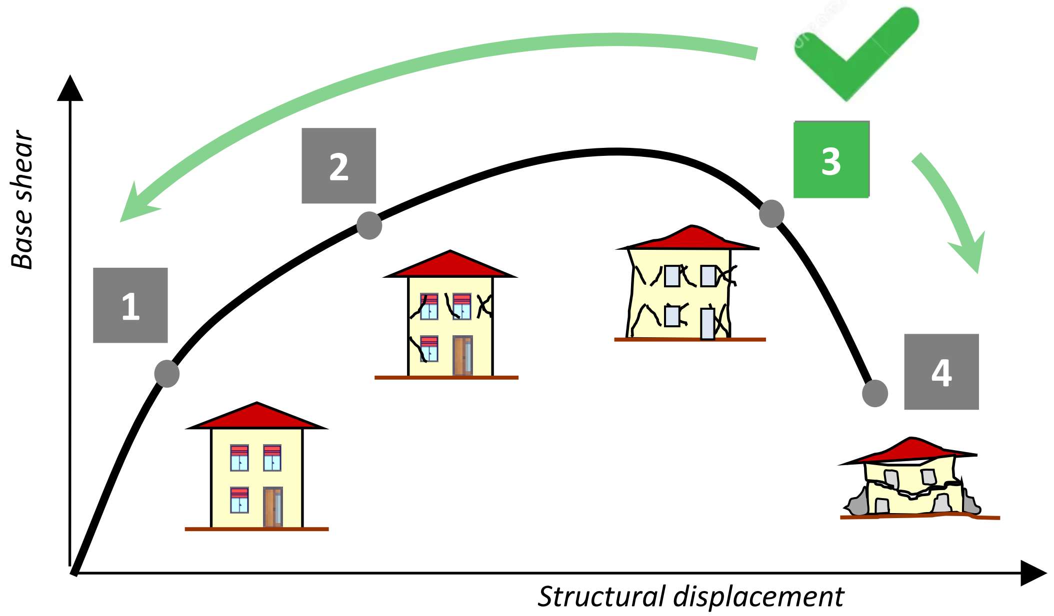
4.5 Compliance criteria for new structures

4.5.1 General

To satisfy the seismic performance requirements for new structures according to EN 1998:

- the requirements for design verification principles shall be applied (detailed in 4.5.2);
- and the <u>non-exceedance of the SD limit state shall be verified</u>.

NOTE 1 EN 1998 is conceived in such a way that, for a large majority of new structures, the SD non-exceedance requirement implies avoiding NC exceedance under a seismic action meaningfully more severe than that of design, as well as avoiding DL exceedance under a seismic action less severe than that of design. Additionally, by taking into account the consequence class of the structures, the SD non-exceedance requirement implicitly contributes to some extent to the fully operational performance.



1. Fully Operational (OP)
2. Damage Limitation (DL)
3. **Significant Damage (SD)**
4. Collapse (NC)

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Date: 2022-01-01

prEN 1998-1-2:2022

Eurocode 8: — Design of structures for earthquake resistance — Part 1-2: Rules for new buildings

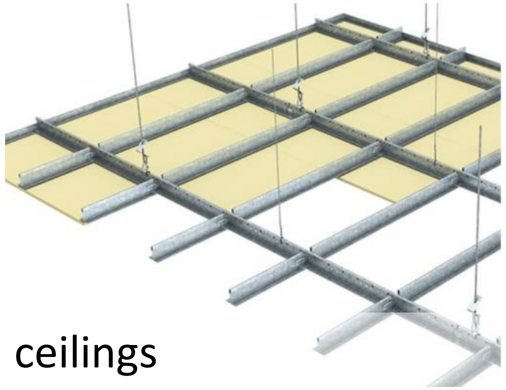
Ancillary elements

Elements of buildings that might, in case of failure, pose risks to human life or affect the main structure of the building or the services of facilities, shall, together with their supports, be verified to resist the design seismic action in two orthogonal horizontal directions.


claddings


parapets


partitions


ceilings


railings


chimneys

Verification at Significant Damage (SD) limit state – Section 7 (ANCILLARY ELEMENTS)

The ancillary elements, as well as their connections to the structure, should be verified for the seismic design situation in terms of acceleration and displacement in two orthogonal horizontal directions

Horizontal seismic force, acting at the centre of mass of the ancillary element in the most unfavourable direction:

$$F_{an} = \gamma_{an} m_{an} S_{an}/q_{an}'$$

m_{an} is the mass of the element

S_{an} is the value in the floor acceleration spectrum determined for two horizontal directions

γ_{an} is the performance factor of the element

q_{an}' is the period dependent behaviour factor of the ancillary element

Verification at Significant Damage (SD) limit state – Section 7 (ANCILLARY ELEMENTS)

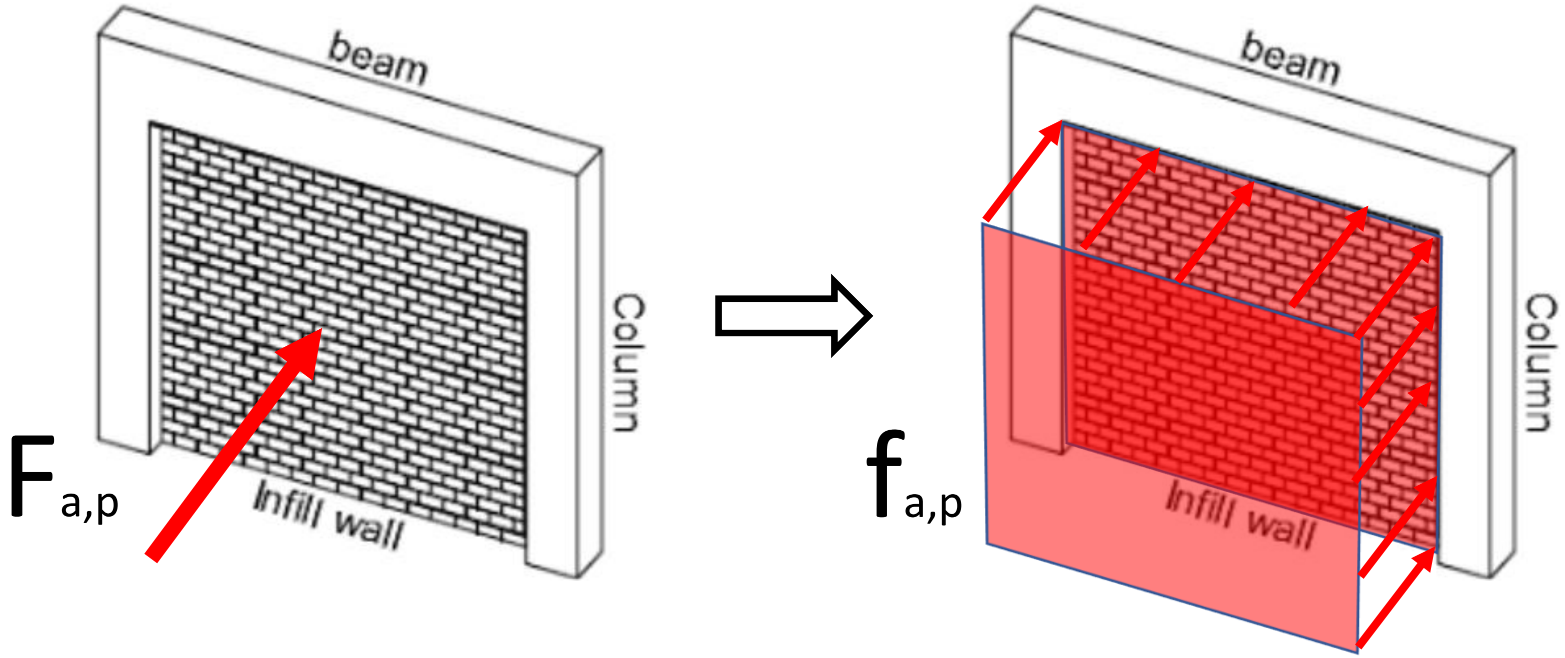
In case of ancillary elements with uniformly distributed mass (e.g. partition wall), the resultant force F_{an} may be distributed proportionally to the mass or its deformed shape.

$$f_{a,p} = F_{a,p}/(h_p\ l_p)$$

$F_{a,p}$ is the horizontal seismic force applied at the centre of the element;

h_p is the length of the element;

l_p is the height of element.



Verification at Significant Damage (SD) limit state – Section 7 (ANCILLARY ELEMENTS)

Performance factor of the element

The performance factor γ_{an} of ancillary elements should not be smaller than 1,0.

Except for elements participating to safety systems the value of γan is 1,0*

For anchorage elements of machinery or for equipment participating to safety systems, the performance factor γ_{an} should be 1,5*.

* unless a relevant Authority or the National Annex or, in the absence of such guidance, the relevant parties for a specific project set different values

Behaviour factor of the ancillary element

Table C.1 — Maximum values of q_{an} for ancillary elements

Type of ancillary element	q_{an}
Elements not able or not allowed to dissipate energy by inelastic deformation:	
Cantilevering parapets or ornamentations Signs and billboards Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height	1
Elements dissipating energy by inelastic deformation:	
Exterior and interior walls Partitions and façades, claddings 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 Anchorage elements for permanent cabinets and book stacks supported by the floor Anchorage elements for false (suspended) ceilings and light fixtures	2

Verification at Damage Limitation (DL) limit state – Section 6 (VERIFICATION OF STRUCTURAL MEMBERS TO LIMIT STATES)

Limitation of interstorey drift

Design interstorey drift at DL Limit state

$$d_{r,DL} \leq \lambda_{ns} h_s$$

$d_{r,DL}$ is the design interstorey drift calculated for the DL Limit state

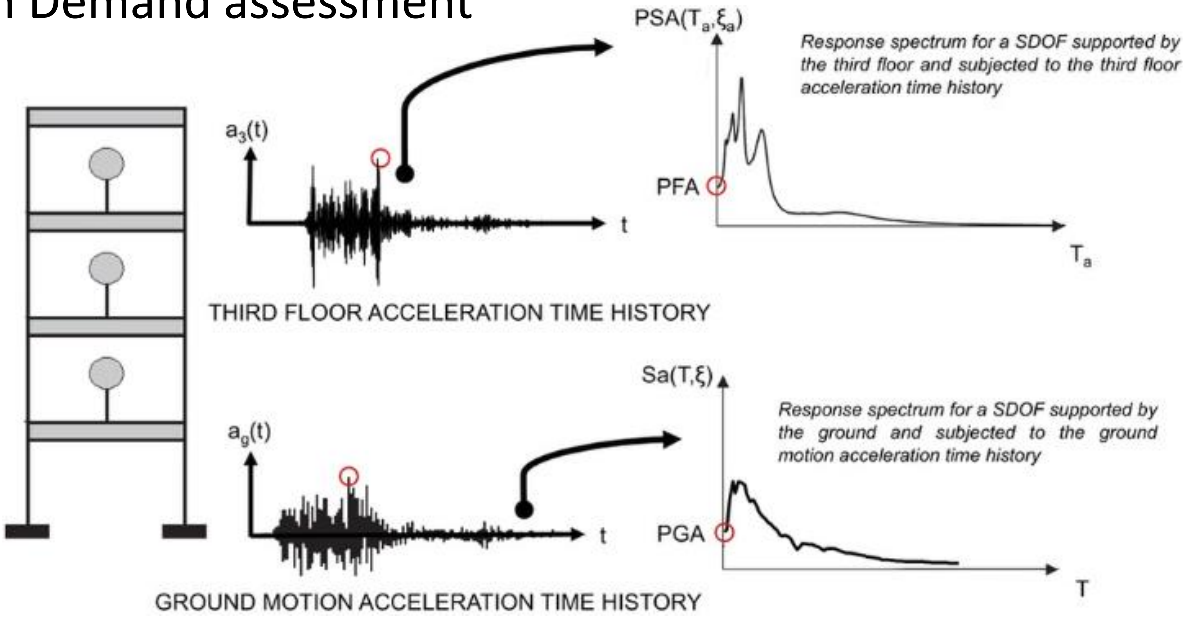
h_s is the storey height

λ_{ns} coefficient accounting for sensitivity of ancillary elements to interstorey drift

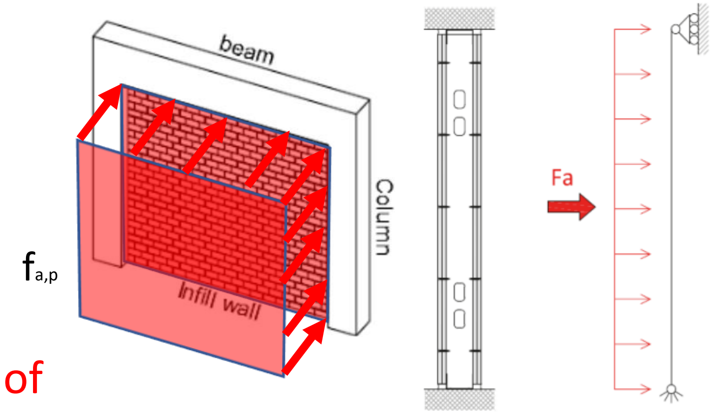
λ_{ns}	Type of ancillary elements
0,0025	for buildings having ancillary elements of unreinforced masonry units of Group 4 attached to the structure
0,0045	for buildings having ancillary elements of brittle materials attached to the structure, in particular unreinforced masonry with clay units of Groups 1, 2 or 3 with a thickness greater than 200 mm and the normalised mean compressive strength $f_b \geq$ 3MPa
0,0075	for buildings having ductile ancillary elements attached to the structure,
0,010	for buildings having ancillary elements fixed in a way so as not to interfere with structural deformations

Nonstructural building elements in the new generation of Eurocodes

- Complexity
  in Demand assessment



- Complexity in
  behaviour/capacity



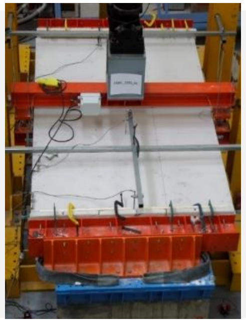
The importance of seismic pre-qualification of non structural elements

X EDIZIONE
SEISMIC
ACADEMY

Contents

- Seismic design issues for nonstructural building elements
- Nonstructural building elements in the current Eurocode 8
- The new generation of Eurocode 8
- Nonstructural building elements in the new generation of Eurocodes
- **Studies developed at University of Naples Federico II**

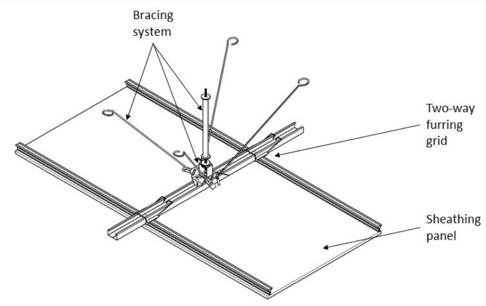
Studies developed at University of Naples Federico II

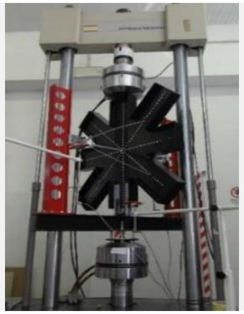




Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023

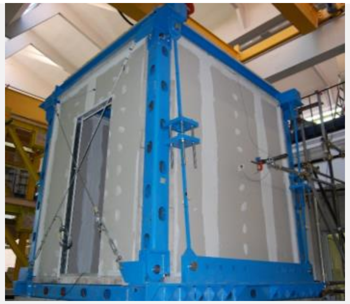




Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017

- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress



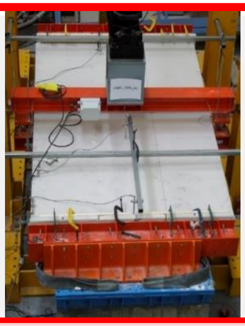

Drywall and suspended ceilings sub-systems

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020



Whole building

- European research project
  ELISSA Project, years 2013-2016



Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023

Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017

- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress

Drywall and suspended ceilings sub-systems

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

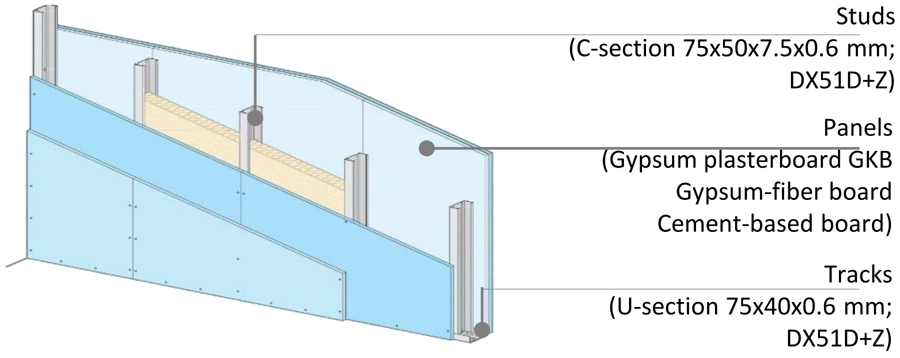
Whole building

- European research project
  ELISSA Project, years 2013-2016

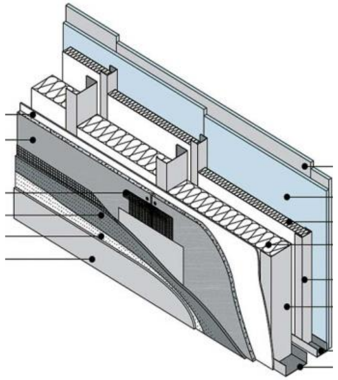
Seismic response evaluation of non-structural lightweight steel drywall building components

The research project is devoted to investigate the seismic performance of lightweight steel gypsum-sheathed interiror partition walls, exterior façade walls and suspended continuous ceilings and the interaction between them and other structural elements.

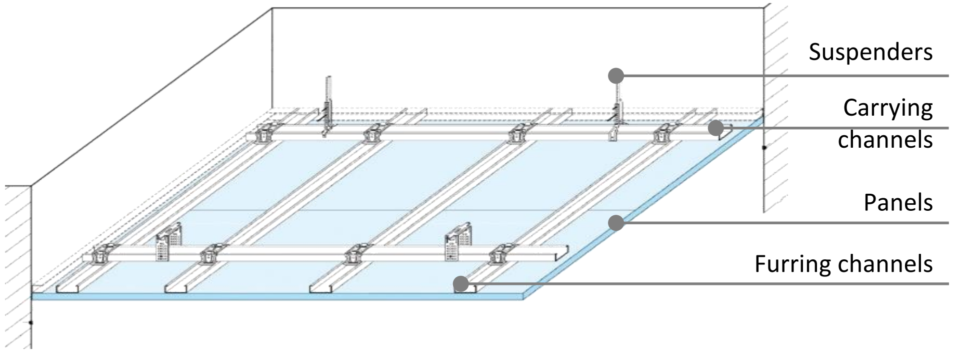
Interior partition walls



Exterior façade walls



Suspended continuous ceilings

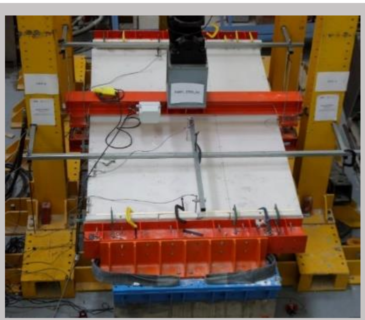


General experimental program

	Test type	no. tests
Material and component tests	Steel material	12
	Self-tapping and self-drilling screws	42
	Sheathing panels	30
	Panel-to-steel connections	60
Drywall tests	In-plane quasi-static reversed cyclic tests	12
	Out-of-plane monotonic tests	22
	Out-of-plane dynamic identification tests	11
Drywall and suspended ceilings sub-systems	Dynamic identification and earthquake tests	83 + 75 tests on 4 protoypes
	Total no. of tests	*349*







Tests on materials, components and connections

Since the response of lightweight steel gypsum board partition walls is strongly influenced by the local response of the different materials composing these systems, a large number of **tests on materials** and **components** was carried out in order to characterize their mechanical properties.

Tensile tests on steel material

Shear tests on self-tapping and self-drilling screws

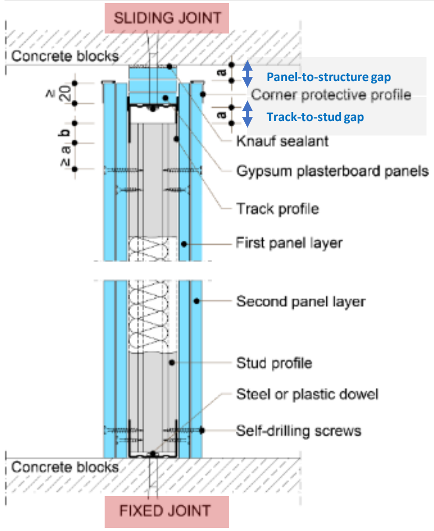
Bending tests on sheathing panels

Shear tests on screwed panel-to-steel connections

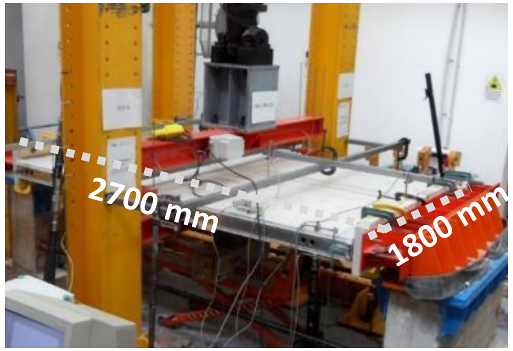
Drywall tests: Out-of-plane quasi-static monotonic and dynamic identification tests

Experimental assessment of the out-of-plane seismic response of indoor partition walls for evaluating the **wall resistance** and the **fundamental vibration period.**

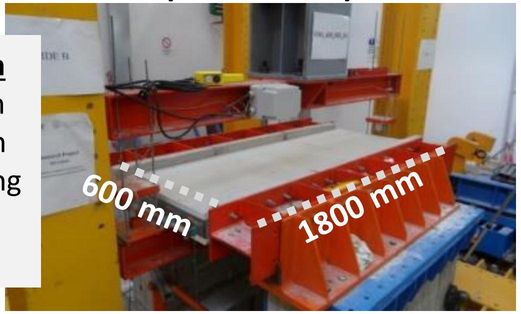
Specimen typologies



Conventional partition (H=2700 mm)



Non-conventional partition (H=600 mm)



<u>Parameters under investigation</u>

- **wall height:** 600 or 2700 mm
- **stud spacing:** 300 or 600 mm
- **joint type-gap:** fixed/sliding (a=0 mm/20mm/30 mm)
- **dowel type:** plastic or steel

a= 0

a= 20

a= 30

Steel dowel

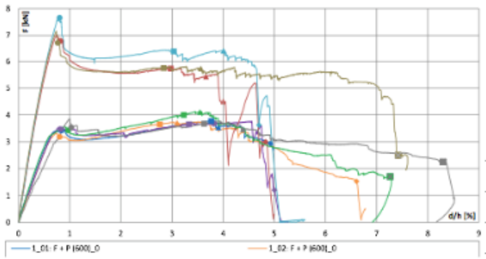
Plastic dowel

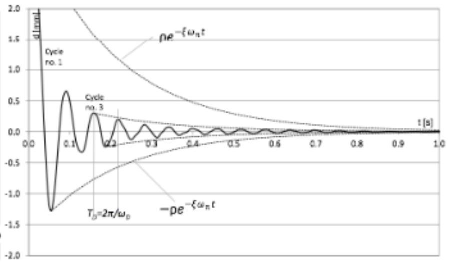
Test program and main results

Conventional partition

MONOTONIC (QUASI-STATIC) TESTS (No. 14)
for evaluating the **wall resistance (F_{Rd})**
(Collapse phenomena were to the wall framing local buckling)

STEP-RELAXATION (DYNAMIC) TESTS (No. 11)
for evaluating the **fundamental vibration period** (T_a)





Non-conventional partition

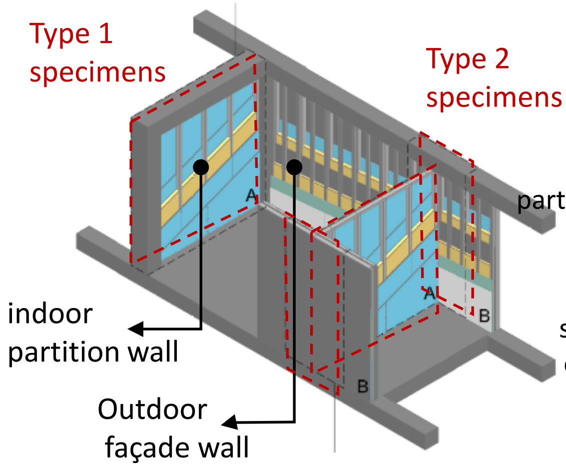
MONOTONIC (QUASI-STATIC) TESTS (No. 8)
for evaluating the behaviour of joints between partition walls and reinforced concrete surrounding structures.
(Collapse phenomena were related to the joint collapse)

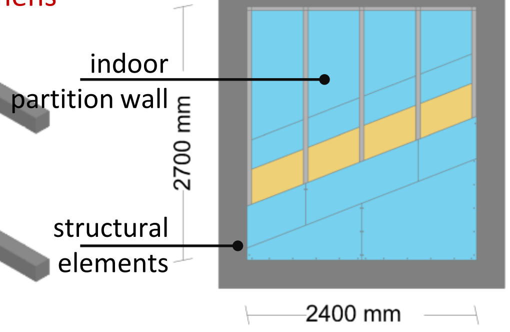
Total out-of-plane monotonic tests: 22
Total dynamic identification tests: 11

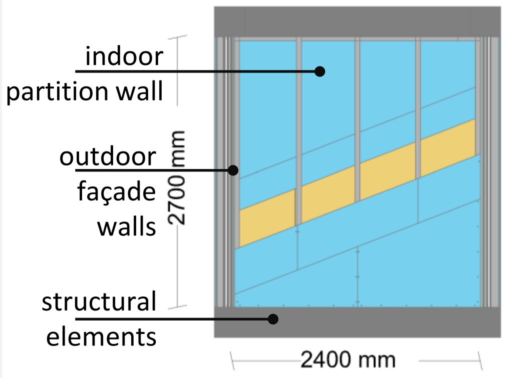
Drywall tests: In-plane quasi-static reversed cyclic tests on partition walls

Experimental assessment of the in-plane seismic response of the interior partition walls, also considering the interaction with exterior façade walls, and the **related damage levels** in accordance with the inter-storey drift limits defined by the European code.

Specimen typologies







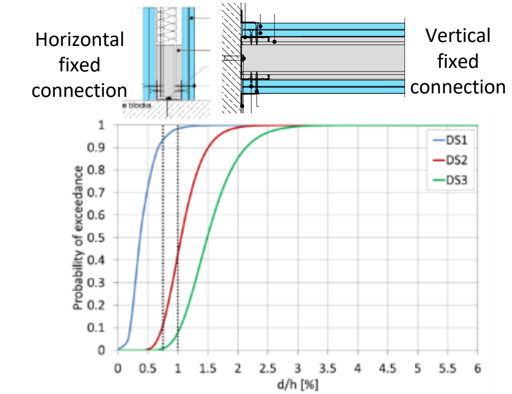
Total tests: 12

Parameters under investigation

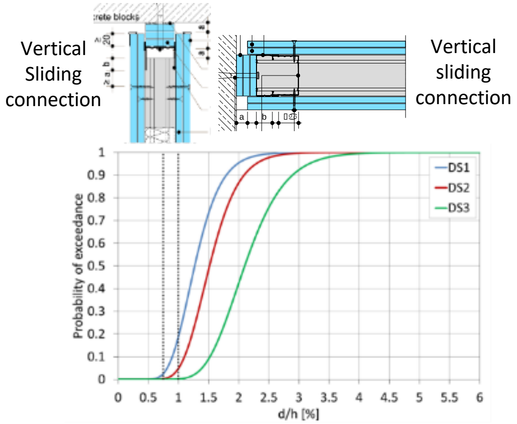
- **Type of horizontal and vertical connections to structure:** Fixed/sliding
- **Stud spacing:** 300 or 600 mm
- **Type of sheathing panel :** standard gypsum/gypsum fibre boards
- **Type of jointing finishing:** glass fibre or paper tape and self-adhesive paper tape

Main results-fragility curves

Type 1 specimens-*Fixed connections*



Type 1 specimens-*Sliding connections*

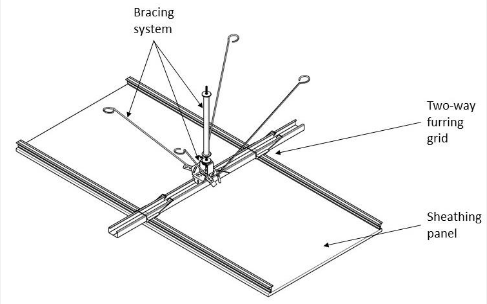


Studies developed at University of Naples Federico II

Guerrasio-UNINA Project

Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020
- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023



Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017
- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress

Drywall and suspended ceilings sub-systems

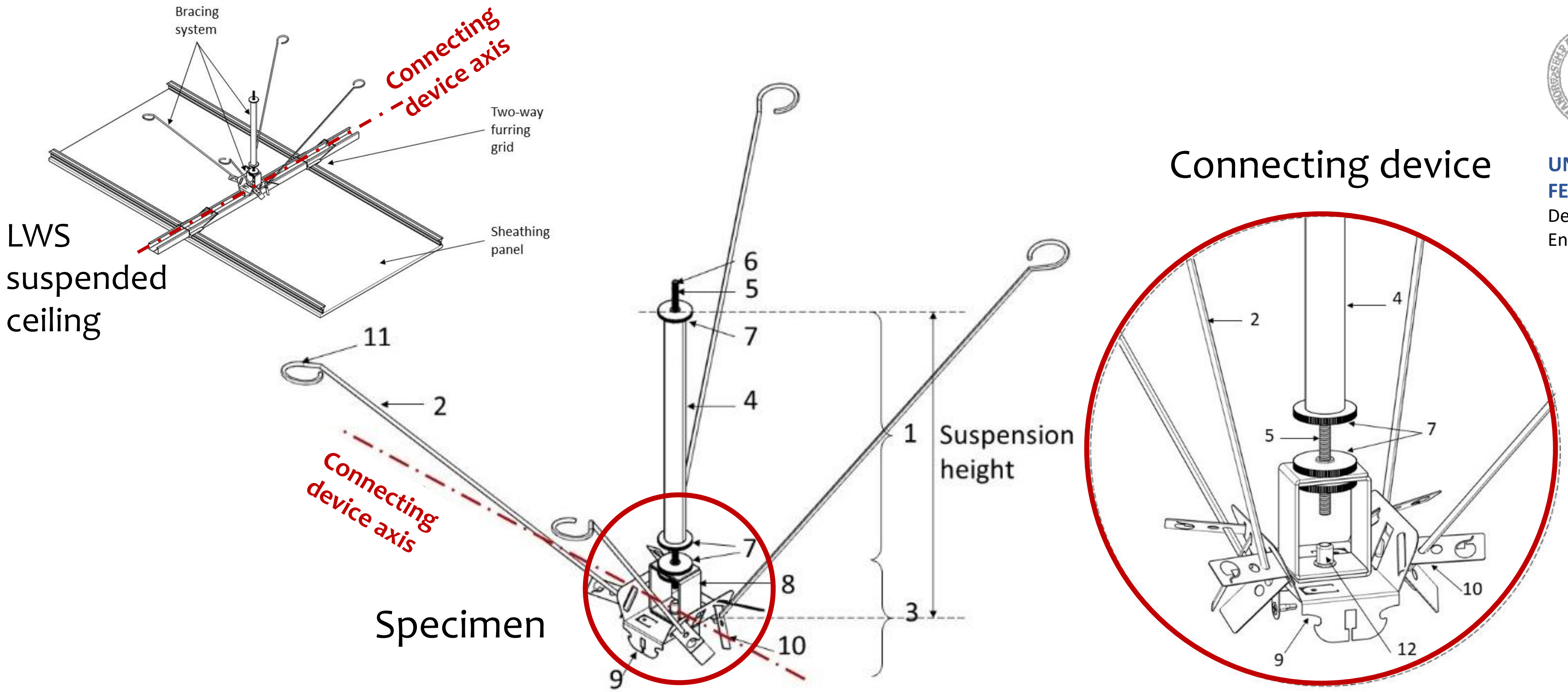
- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

Whole building

- European research project
  ELISSA Project, years 2013-2016

Experimental characterization of the structural response of the constructional system developed for anti-seismic suspended ceilings by Antonio Guerrasio s.r.l.

UNIVERSITY OF NAPLES FEDERICO II
Department of Structures for Engineering and Architecture

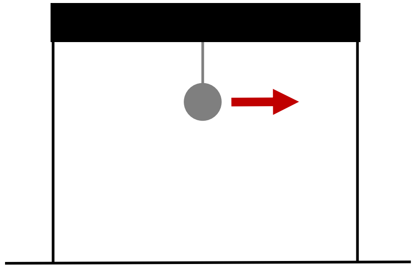


1. Compression strut (4. Circular hollow section profile; 5. Threaded bar; 6. Connecting point of the threaded bar; 7. Threaded washers)
2. Diagonal bars (11.Buttonhole of the diagonal bars)
3. Connecting device (8. U section profiles; 9. Shaped sheet; 10. Clips; 12. Screw)

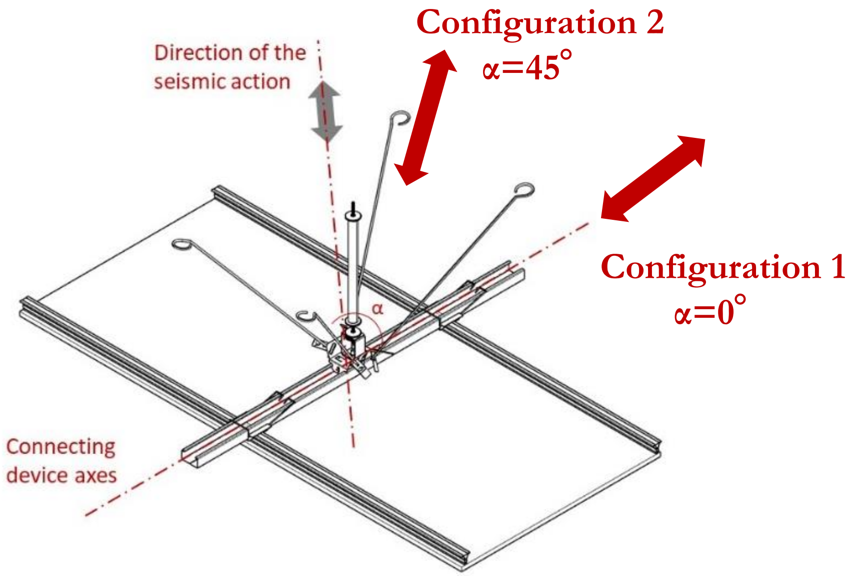
Tests carried out at the Laboratory of the Department of Structures for Engineering and Architecture (DIST), University of Naples "Federico II"

Basic assumptions:
(1) tests were carried out with a universal testing machine
(2) tests were finalised to evaluate the behaviour of the bracing system considering the ceiling as an acceleration-sensitive non-structural component
(3) the same test set-up was adopted for two different horizontal directions of the seismic action

Universal testing machine



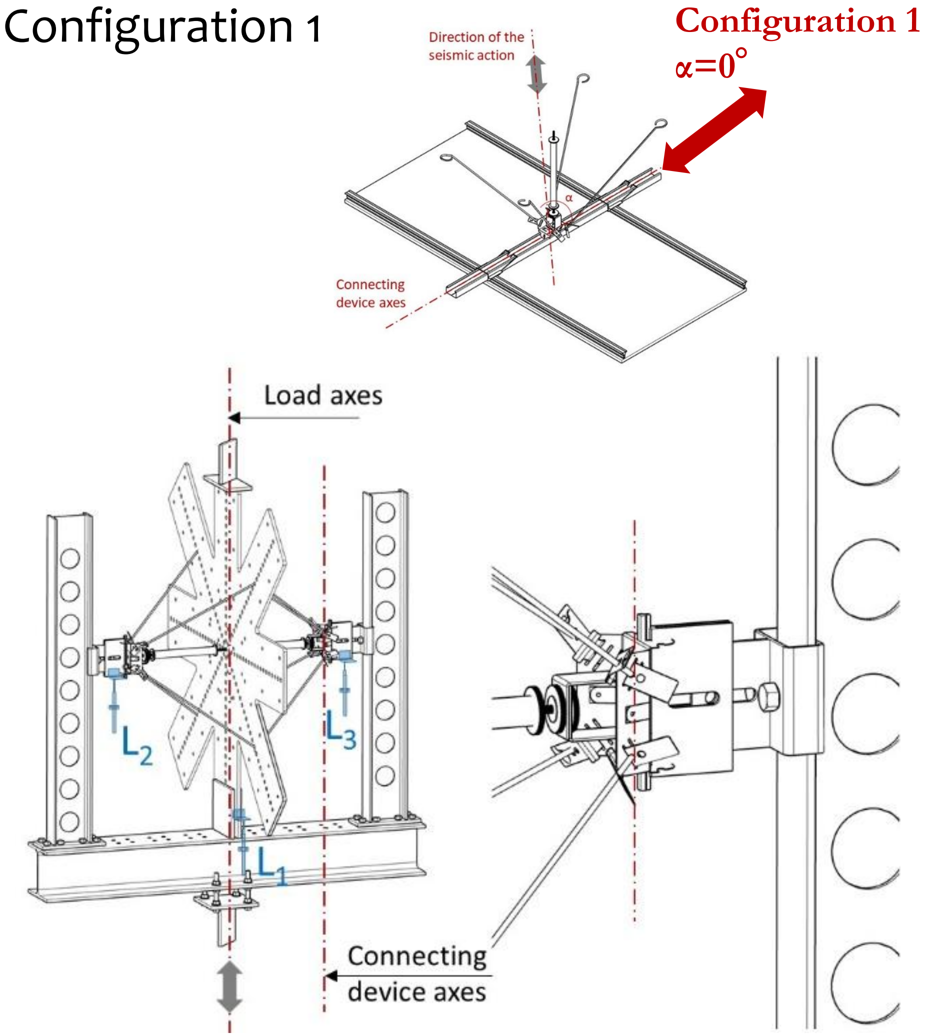
Acceleration-sensitive non-structural component



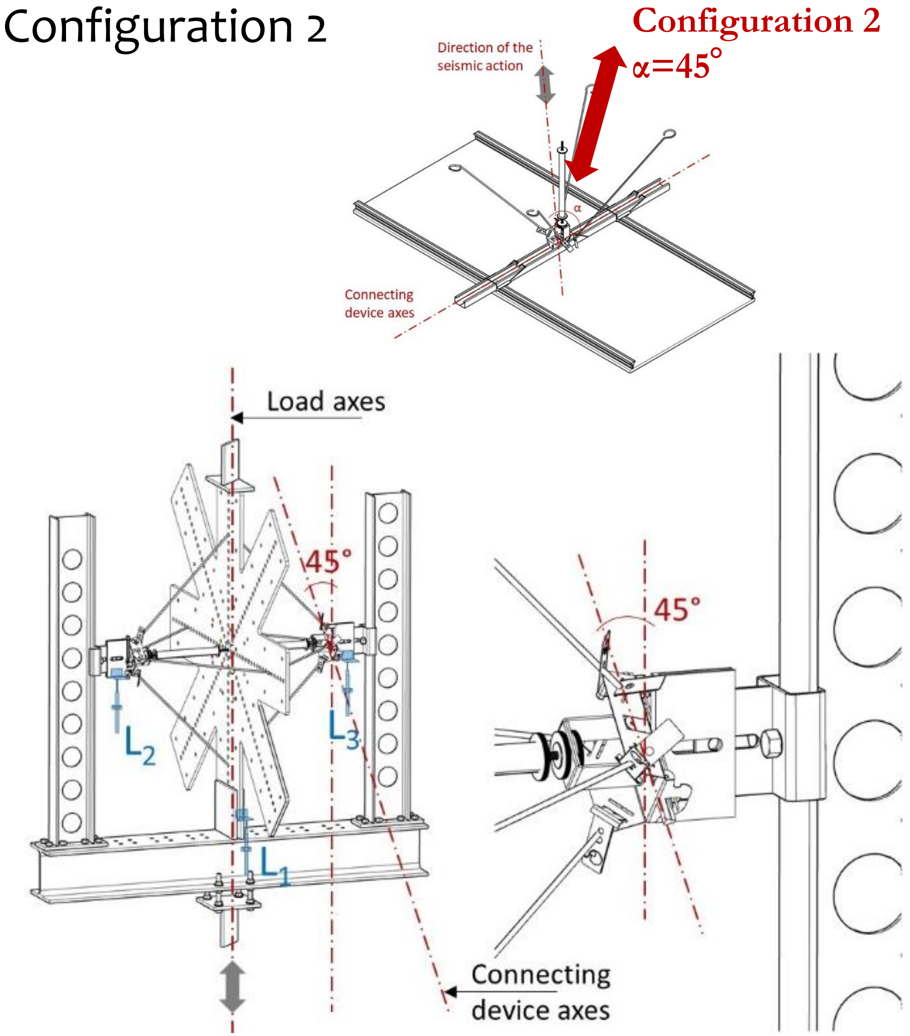
Horizontal directions of the seismic action

TEST SET-UP

Configuration 1



Configuration 2

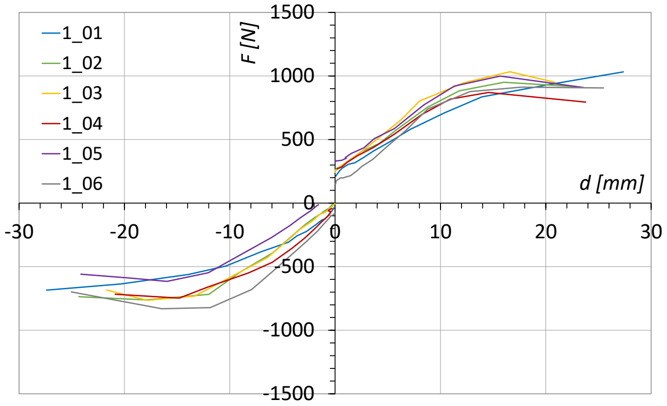


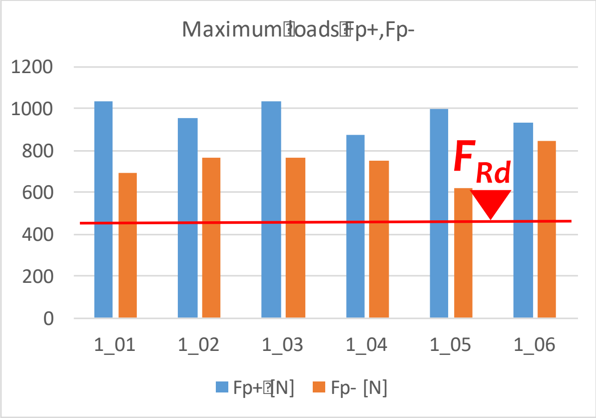
TEST RESULTS

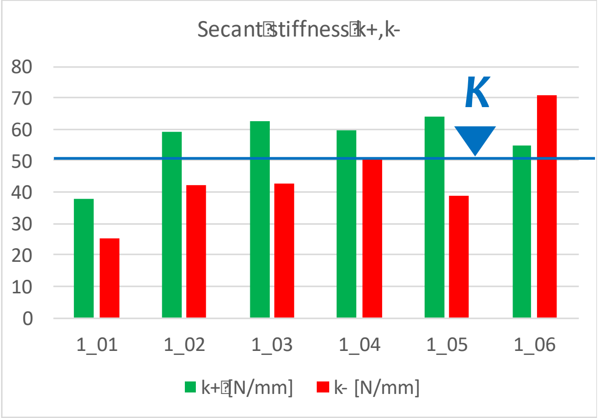
Backbone curves

F_p^+: maximum load F reaching during the test for d>0;
F_p^-: maximum load F reaching during the test for d<0;
$k^+ = F_p^+/d_p^+$: secant stiffness evaluated for d>0;
$k^- = F_p^-/d_p^-$: secant stiffness evaluated for d<0.

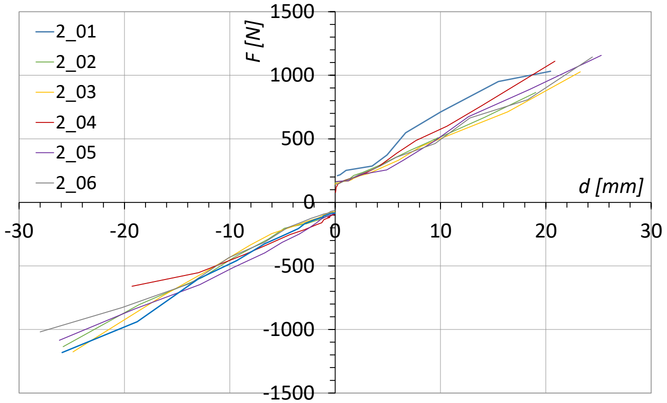
Configuration 1

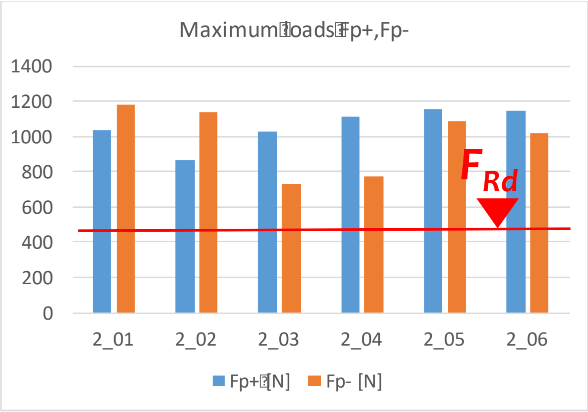


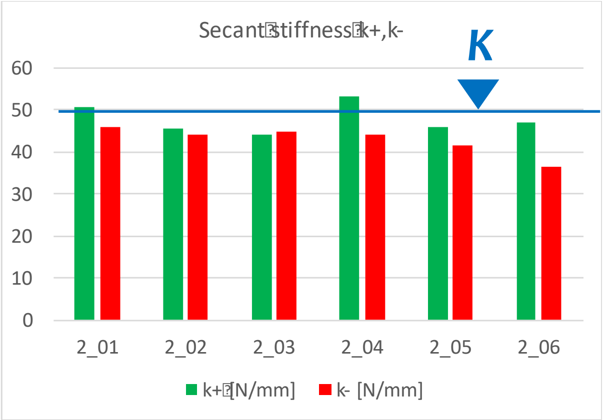




Configuration 2







Configuration 2 slightly stronger than Configuration 1
Configuration 1 slightly stiffer than Configuration 2

Experimental based design resisting force: F_{Rd} = 449 N
Experimental based design stiffness K = 50 N/mm

Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020
- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023

Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017
- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress


Drywall and suspended ceilings sub-systems

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

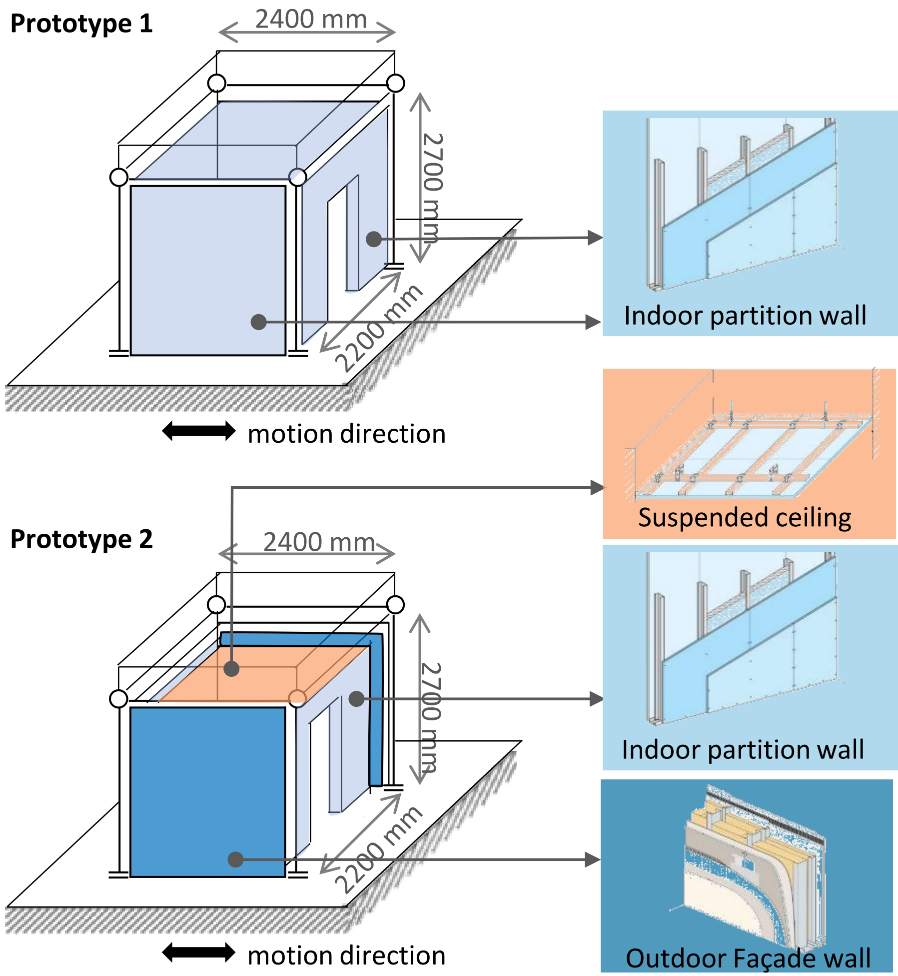
Whole building

- European research project
  ELISSA Project, years 2013-2016

Drywall and suspended ceilings sub-systems: Shake table tests on partition walls, façade walls and suspended ceilings

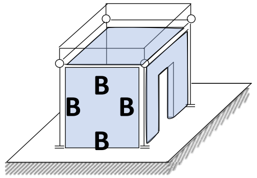
Assessment of the seismic behavior under dynamic loading conditions of four prototypes made of **different non-structural components differently connected** between them and to the structural systems.

Tested prototypes

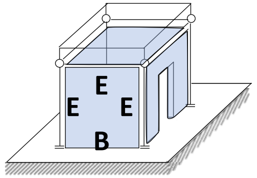


No. of tested prototypes: 4

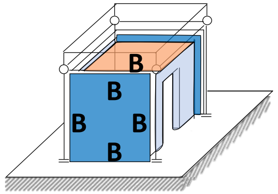
Prototype 1B - Basic



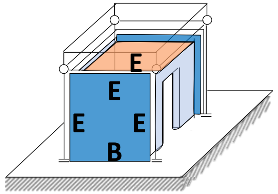
Prototype 1E - Enhanced



Prototype 2B - Basic



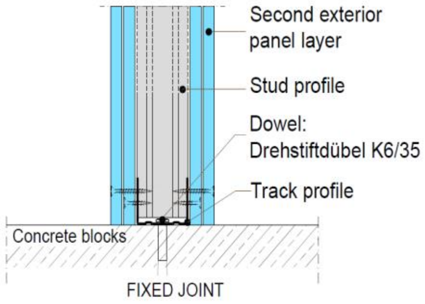
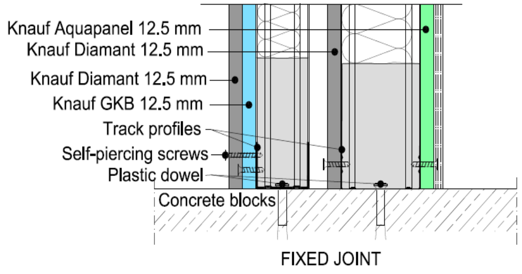
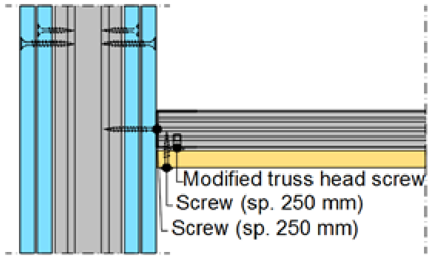
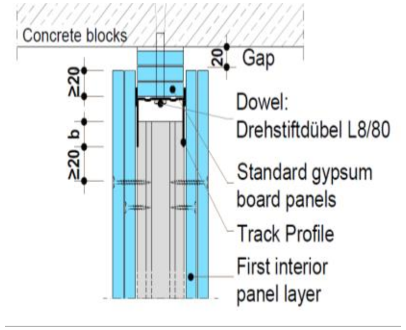
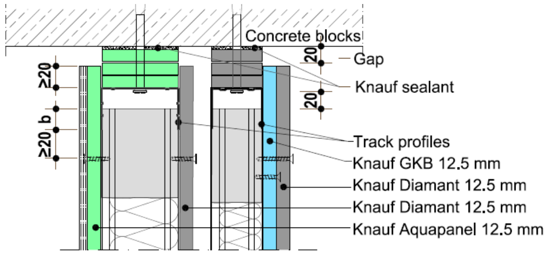
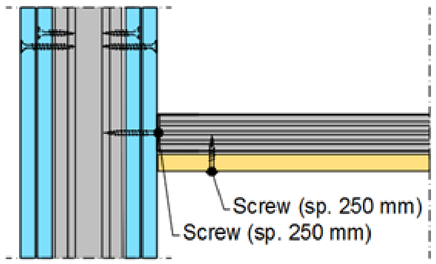
Prototype 2E- Enhanced



B:basic connection; E: enhanced connection

Drywall and suspended ceilings sub-systems: Shake table tests on partition walls, façade walls and suspended ceilings

Connection typologies

	Interior Partition Wall	Exterior Façade Wall	Suspended Ceiling
BASIC SOLUTION FIXED CONNECTIONS			
ENHANCED SOLUTIONS SLIDING CONNECTIONS			

Drywall and suspended ceilings sub-systems: Shake table tests on partition walls, façade walls and suspended ceilings

Observed damage phenomea

Interior partition walls


1. Drop of gypsum dust

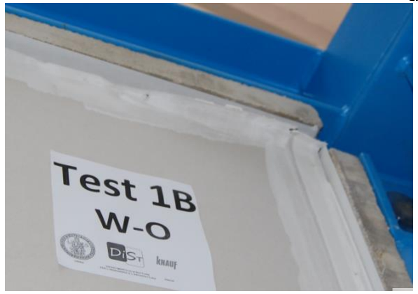
3. Detachment of joint paper


5. Cracks in the panels


4. Detachment between walls and structural elements


6. Corner crushing of panels


8. Collapse of panel-to-frame fixings



9. Rupture of panel portions

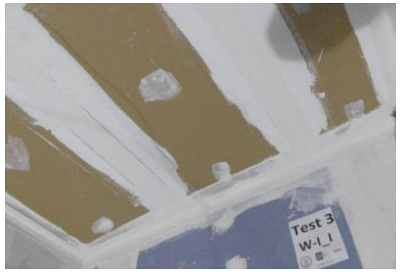
10. Out-of-plane collapse of panel

Exterior façade walls


2. Drop of basecoat dust


7. Crushing of exterior façade wall corner

Suspended ceiling



Very low damage observed for suspended ceiling

Drywall and suspended ceilings sub-systems: Shake table tests on partition walls, façade walls and suspended ceilings
Fragility curves

1 Definition of damage limit-states (DS)

DS1 – superficial damage, it requires minimum repair with plaster, tape and paint

DS2 – local damage of sheathing panels and/or steel frame components, it required the removal and replacement of elements (sheathing panels and/or local repair of steel frame components)

DS3 – severe damage, it requires the replacement of part or whole component

2 DS-damage correlation

The observed damages were associated to the damage limit states depending on the required level of repair

Observed damage phenomena	DS1	DS2	DS3
1. Drop of gypsum and/or plaster dust	•		
2. Detachment of joint tape	•		
3. Detachment between walls and surrounding structural elements		•	
4. Crack in panels		•	
5. Corner crushing of panels		•	
6 Collapse of panel-to-frame fixings		•	
7. Rupture of panel portions			•
8. Out-of-plane collapse of panels			•

3 DS - Drift--Damage correlation

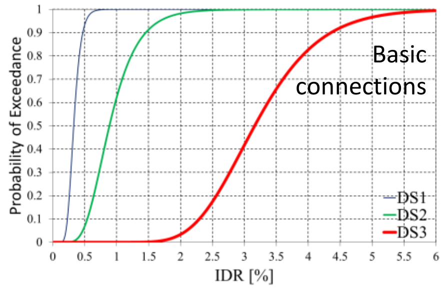
The drift levels triggered the damage limit states were recorded for each specimen and correlated to the damage limit states

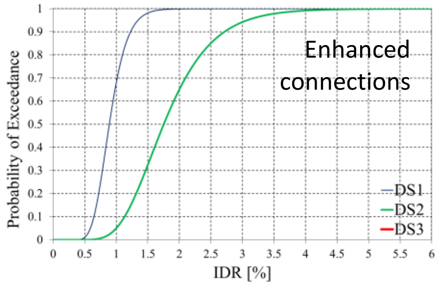
Damage limit states	Interior Partition Walls		
	1_B-I	1_B-II	1_E
	Drift [%]	Drift [%]	Drift [%]
DS1	0.32%	0.28%	0.89%
DS2	0.66%	1.19%	1.39%
DS3	3.12%	3.20%	-

Damage limit states	Exterior Façade Walls	
	2_B	2_E
	Drift [%]	Drift [%]
DS1	0.31	1.11
DS2	1.17	2.44
DS3	3.74	4.54

4 Fragility curves

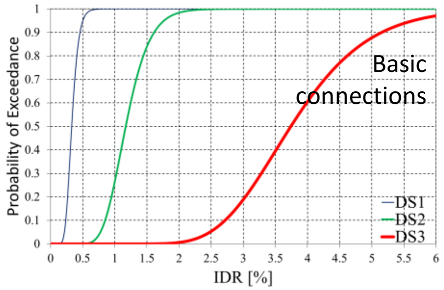
Interior Partition walls

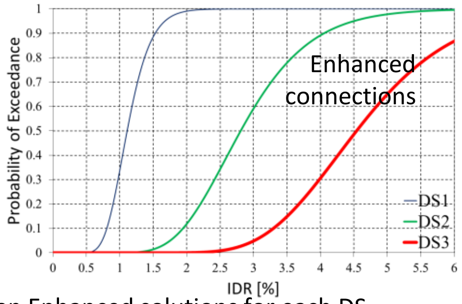




Interior Partition Walls showed an higher seismic fragility than Exterior Façade walls for each DS

Exterior Façade walls





Basic solutions showed an higher fragility than Enhanced solutions for each DS

Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020
- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023

Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017
- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress

Drywall and suspended ceilings sub-systems

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

Whole building

- European research project
  ELISSA Project, years 2013-2016

ELISSA Project

Research funded by European Commission within the Project named "Energy Efficient LIghtweight-Sustainable-SAfe-Steel Construction" (Project acronym: **ELISSA**).

E2B Energy Efficient Buildings

SEVENTH FRAMEWORK PROGRAMME

ELISSA Research Project

Energy Efficient LIghtweight – Sustainable – SAfe – Steel Construction

PARTNERS

Takes the weight off your project.

KNAUF Gips

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ZAE BAYERN

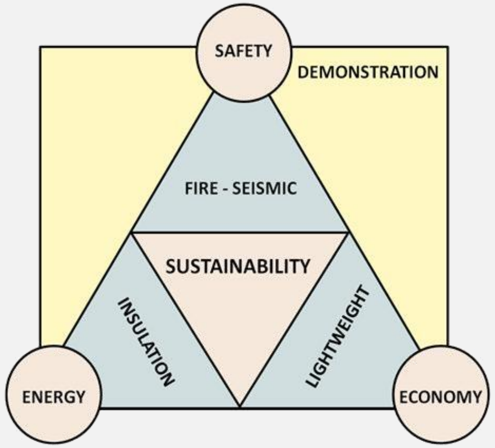
stress

University of ULSTER FireSERT

Wölfel Beratende Ingenieure

Project objective

The ELISSA project was devoted to the development and demonstration of **nano-enhanced prefabricated lightweight Cold-Formed Steel (CFS) skeleton/dry wall constructions** with improved of energy efficiency, fire and seismic safety and sustainability.

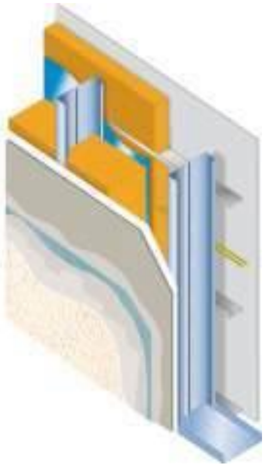


The reference structural system: The COCOON "Transformer"

The system already obtained the European Technical Approval for static loads and the upgrading to withstand also **seismic loads** is one of the main objective of the ELISSA project.

Research goal for DIST

Evaluation of the seismic response of sheathed CFS buildings by means experimental tests on connections, walls and 3D mock-up.




DIBt

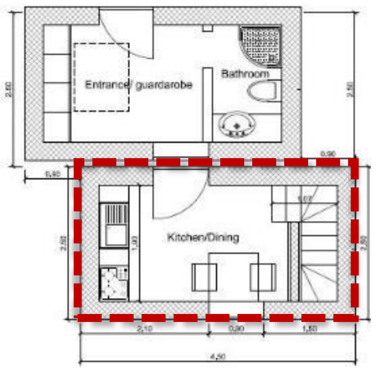
European Technical Approval ETA-11/0105

EOTA

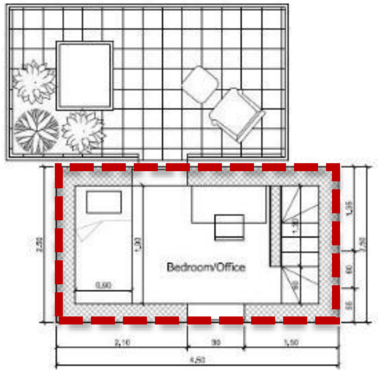
The case study: The "ELISSA house"

The case study consists of a three-rooms two-storeys dwelling named **"ELISSA house"**.
The load-bearing structure of ELISSA house is based on CFS frames (walls and floors) produced by COCOON sheathed with gypsum-based board panels produced by KNAUF (Diamant boards for walls and GIFAfloor boards for floors).

1st floor



2nd floor



"ELISSA HOUSE" data

- **3 rectangular modules** of plan dimensions **2.5 x 4.5 m**, horizontally and vertically jointed
- **Two storeys building**
- **Total gross area:** 34 m^2 + terrace
- **Total height:** 5.4 m

The Elissa Mock-up

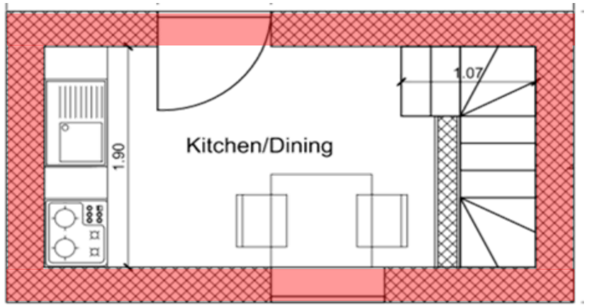
ELISSA MOCK-UP data

2 rectangular modules of plan dimensions 2.5 x 4.5 m, vertically jointed

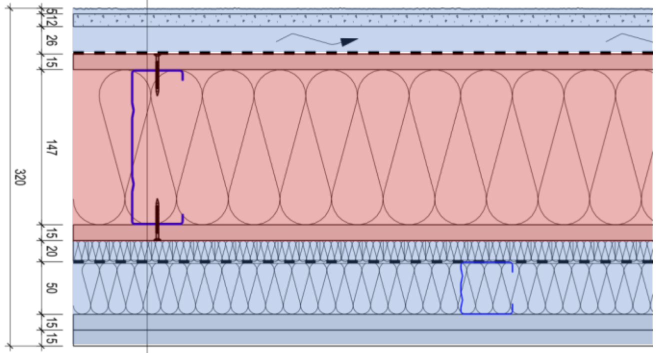
- Two storeys building
- Total gross area: 22.5 m^2
- Total height: 5.4 m
- Weight of the complete building (w/ finishing) : 102 kN (**4.53 kN/m^2**)
- Weight of the structural part (w/o finishing): 46 kN (**2.04 kN/m^2**)

Structural and non-structural building components

Walls



Aquapanel Outdoor plasterboard with render system, 12.5 mm
Knauf slotted hat profile FLV 25/100 with air cavity, 25 mm
Knauf Insulation LDS 0.04 membrane
Knauf Diamant, 1 x 15.0 mm
Structure Cocoon C147/50/1.5 mm, centered at 625 mm
Knauf Insulation mineral wool, FCB 035, 147 mm
Knauf Diamant, 1 x 15.0 mm
Vacuum Insulation Panels, 20 mm
Knauf profile CW50/0.6 mm, centered at 625 mm
Knauf Insulation mineral wool, 50 mm
Knauf Diamant, 2 x 15.0 mm

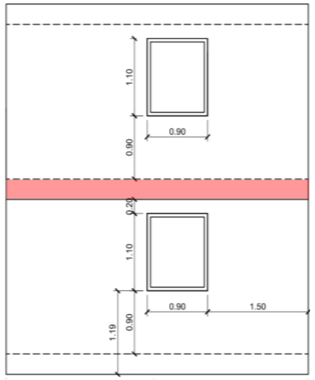


Floor/roof

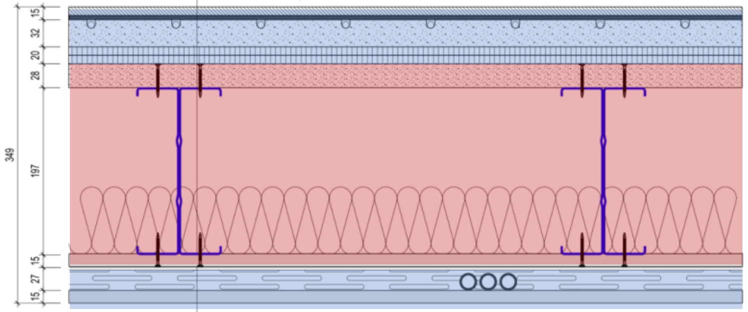
Structural elements

Non-structural elements

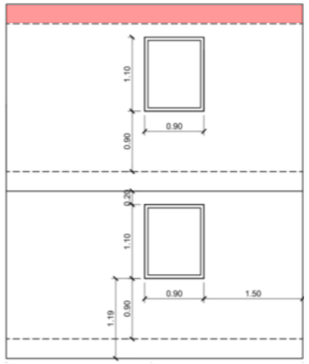
Floor



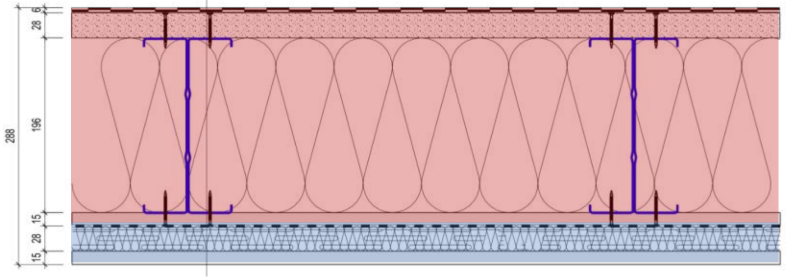
Floor covering
Floor heating / cooling system Knauf GIFAfloor Klima, 32 mm
Impact sound insulation Knauf WF, 2 x 10 mm
Load panels Knauf GIFAfloor, 28 mm
Structure Cocoon DT 2xC197/50/2.0 mm, centered at 500 mm
Knauf Insulation mineral wool, max. 180 mm
Knauf Diamant, 1 x 15.0 mm
Knauf resilient channel 60/27/0.6 mm, 27mm, centered at 500 mm
Knauf Diamant, 1 x 15.0 mm



Roof



Roof sealing film
Knauf GIFAfloor, 28 mm (load panel)
Structure Cocoon DT 2xC197/50/2.0 mm, centered at 500 mm
Knauf Insulation mineral wool, FCB 035, 200 mm
Knauf Insulation vapor barrier LDS 10 Silk
Knauf Diamant, 1 x 15.0 mm
Knauf resilient channel 60/27/0.6 mm, 27mm, centered at 500 mm
Aerogel high performance insulation, 30 mm
Knauf Diamant, 1 x 15.0 mm



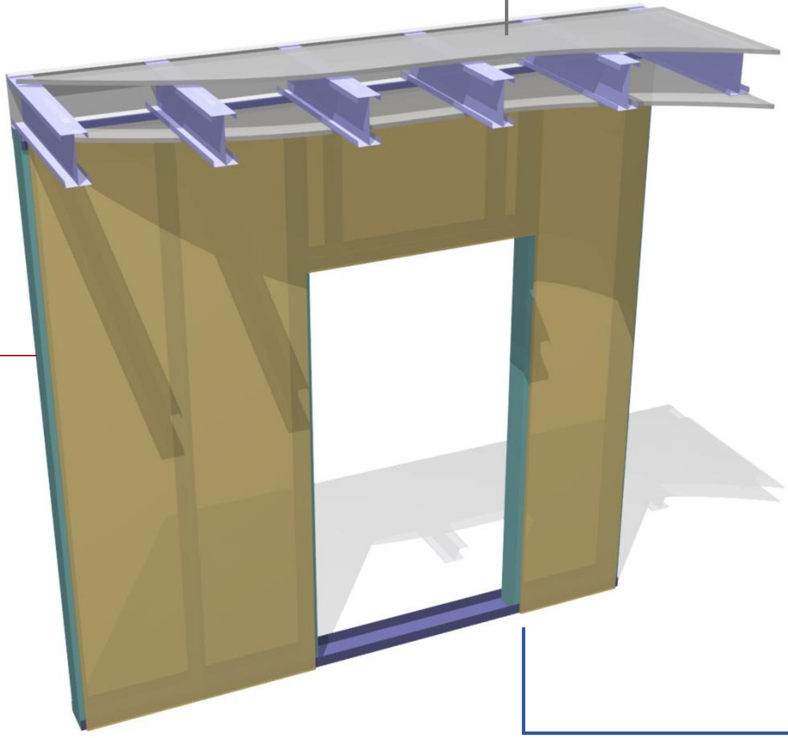
Test type		no. tests
MICRO-SCALE **Component (connections) tests**	Panel-to-steel connections for walls	11
	Panel-to-steel connections for floors	7
	Steel-to-steel connections	15
MESO-SCALE **Sub-structure (wall) tests**	In-plane monotonic tests	1
	In-plane quasi-static reversed cyclic tests	3
MACRO-SCALE **Shake table tests on the ELISSA mock-up**	Dynamic identification and earthquake tests	16 + 28 on 1 prototypes (w/ and w/o finishing)
	Total no. of tests	***81***

Micro-Scale tests: shear tests on connections

Panel-to-steel connections for walls

Total tests: 11

Balistic nails 2,2mm

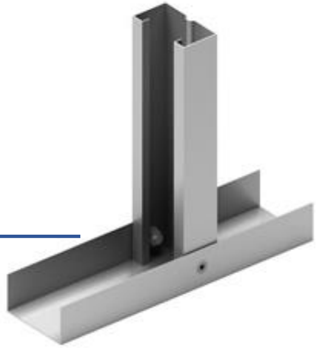


Panel-to-steel connections for floors

Balistic nails 3,4mm

Total tests: 7

Steel-to-steel connections

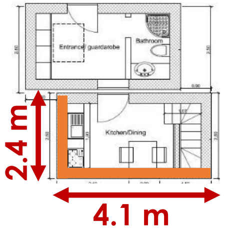


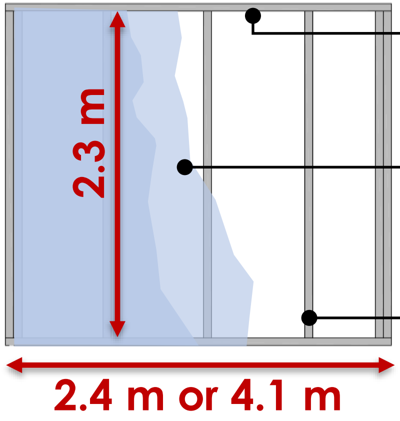
Clinching 8mm

Total tests: 15

Meso-Scale tests: in-plane monotonic and cyclic tests on sub-structures

Specimen typologies and test program





Wall tracks: U150/40/1.5 mm

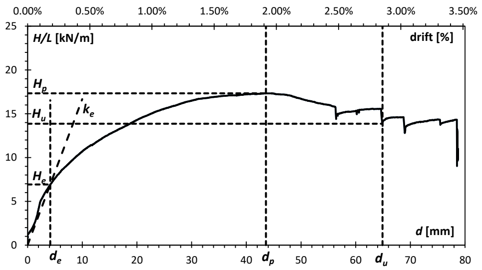
Sheathing panels: 15.0 mm thick gypsum board

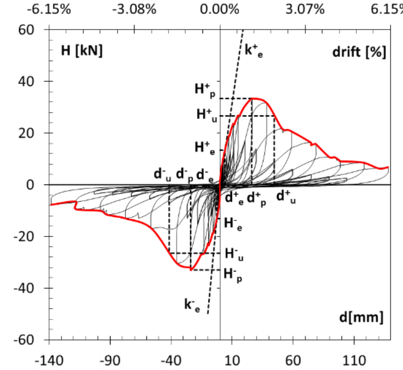
Studs: C147/50/1.5 mm

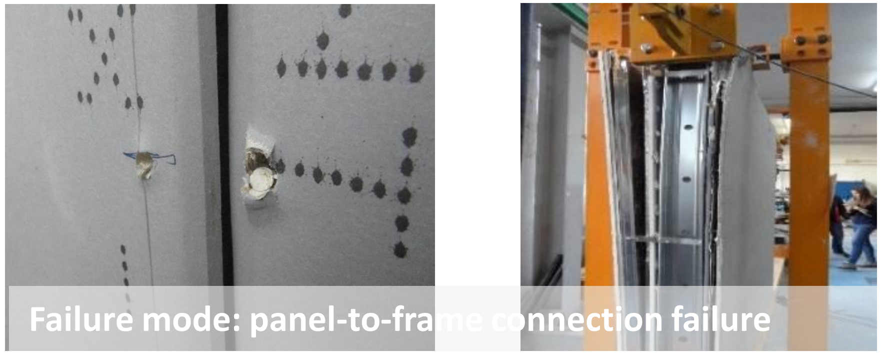
Label	Geometry	Finishing	Load type	No. tests
WS_2400_M	2.4 m x 2.3 m [A]	NO	Monotonic	1
WS_2400_C	2.4 m x 2.3 m [A]	NO	Cyclic	1
WS_4100_C	4.1 m x 2.3 m [B]	NO	Cyclic	1
WF_2400_C	2.4 m x 2.3 m [A]	YES	Cyclic	1

1 monotonic test and 3 cyclic tests

Experimental results







Experimental program for shake table tests

Elissa Mock-up configuration	Dynamic identification tests	Dynamic earthquake tests
Only Structure (Without finishing)	5 tests (0,05 – 0,10 g)	-
Complete construction (With finishing)	11 tests (0,05 – 0,10 g)	28 tests (5 – 150 % Scaling Factor)

Bare structure (without finishing)


Exterior wall panels nailing


Walls and floors lifting


Whole bare structure

Complete structure (with finishing)


Exterior wall panels fixing


Interior wall panels fixing


Whole complete structure

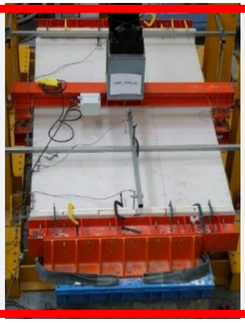
Earthquake test on shake table of the ELISSA mock-up

External view	Internal view (2nd floor)

*Videos recorded during the Earthquake test with scaling factor of **150%***

Studies developed at University of Naples Federico II

HILTI CORPORATION-UNINA Project


Drywalls

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020
- Research project
  HILTI CORPORATION-UNINA Project, years 2020 - 2023

Suspended ceilings

- Research project
  Guerrasio-UNINA Project, years 2016 - 2017
- Research project
  Knauf Italy-UNINA Project, years 2019 – in progress

Drywall and suspended ceilings sub-systems

- Research project
  Knauf Gips KG-UNINA Project, years 2012 - 2020

Whole building

- European research project
  ELISSA Project, years 2013-2016

Research objectives

- Investigate the global seismic response of full-scale drywall partitions in terms of strength and stiffness and in terms of damage suffered.
- Seismic demand evaluation of Power Actuated Fasteners, employed for the connections between wall and surrounding elements.
- Evaluation of seismic fragility through the construction of Fragility Curves for groups of walls with similar characteristics.

Power Actuated Fasteners

For the connections between wall and surrounding elements ***Hilti X-X*** *Power Actuated Fasteners (PAF)* were employed.

Power Actuated Fasteners

Power Actuated Fastening Tool

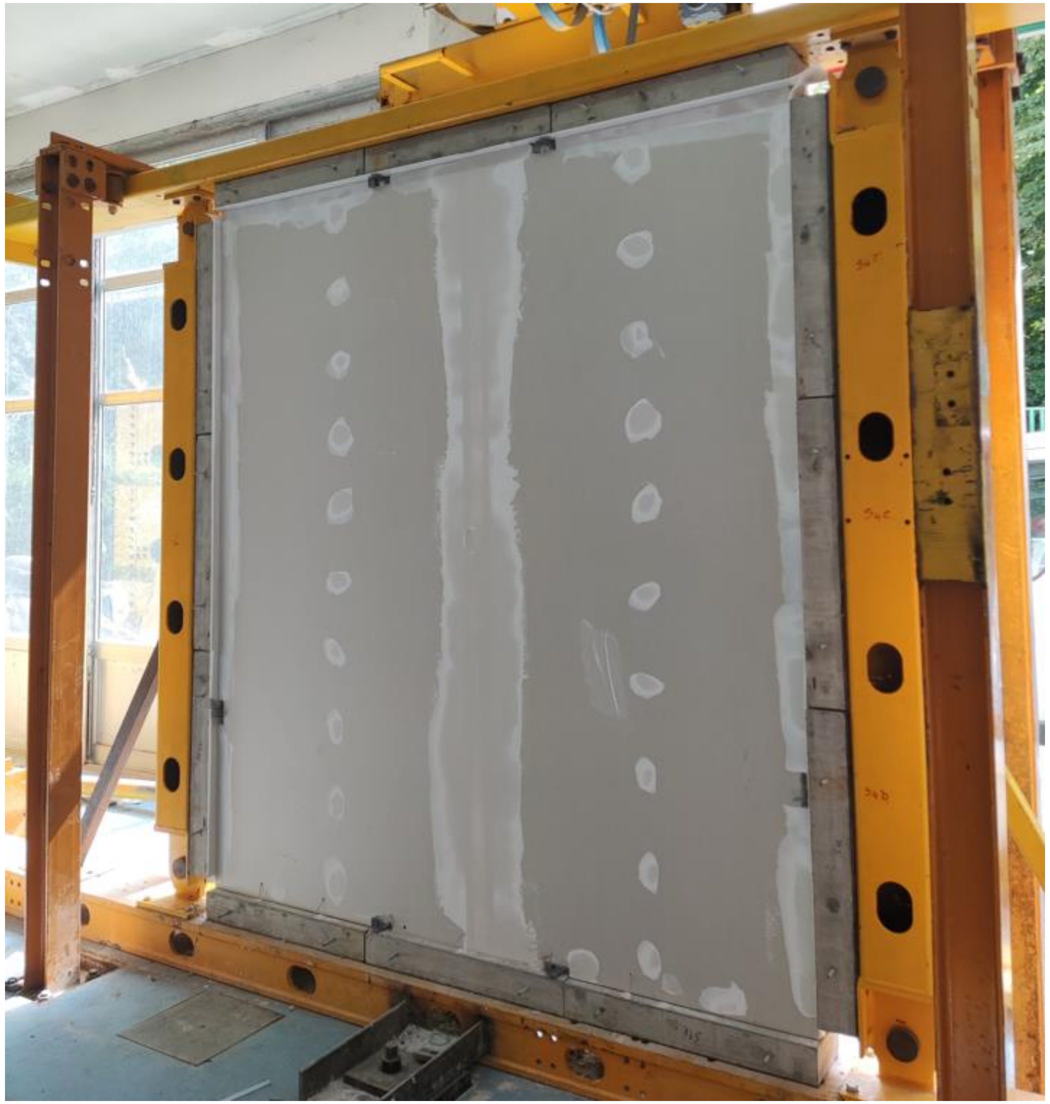
Experimental programme - Specimens description

The experimental activity was carried out on a full-scale typical LWS drywall partition.
All the walls had dimensions of 2300 mm x 2600 mm x 125 mm (length x height x thickness).

The partition wall framing was made of:

- U-shaped track profiles
- C-shaped lipped stud profiles spaced at 600 mm on the centre

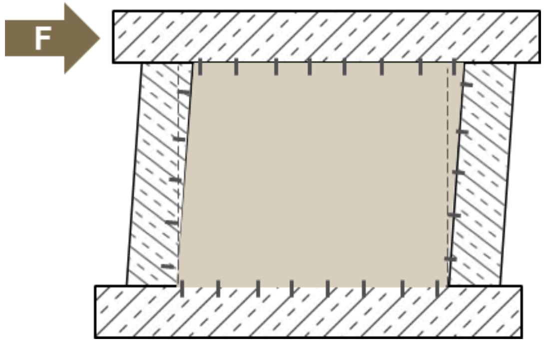
The frame was sheathed on both exterior and interior faces with two layers of 12.5 mm thick standard gypsum wall boards (GWBs).

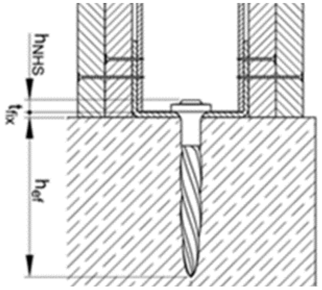


Experimental programme - Test configurations

The experimental activity involved tests on SEVEN walls having 3 main configurations.

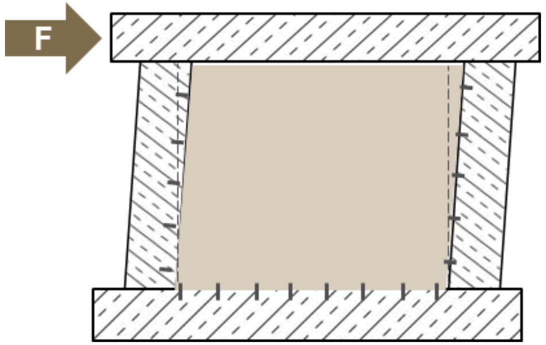
Configuration 1:
walls fixed to concrete base material on 4 sides
REF1, REF 2, REF3

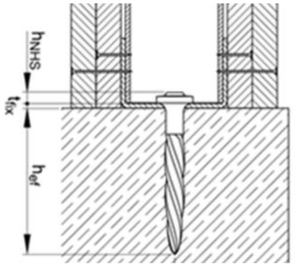




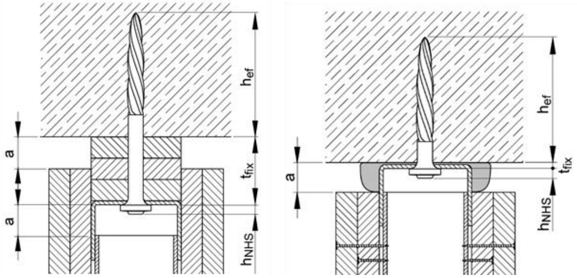
All connections

Configuration 2:
walls fixed to concrete base material on 3 sides (sliding top)
CON_Sw/G, CON_Sw/oG



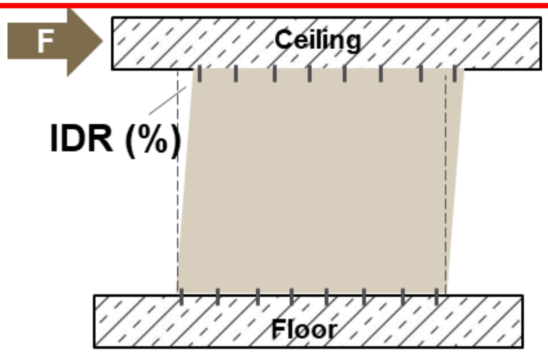


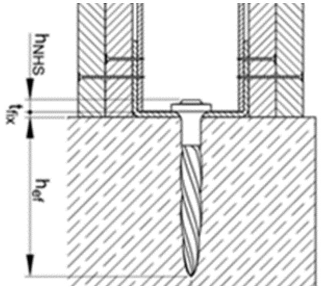
Bottom and side



Top connections

Configuration 3:
walls fixed to concrete base material on 2 sides (no return walls)
SIDE1, SIDE2

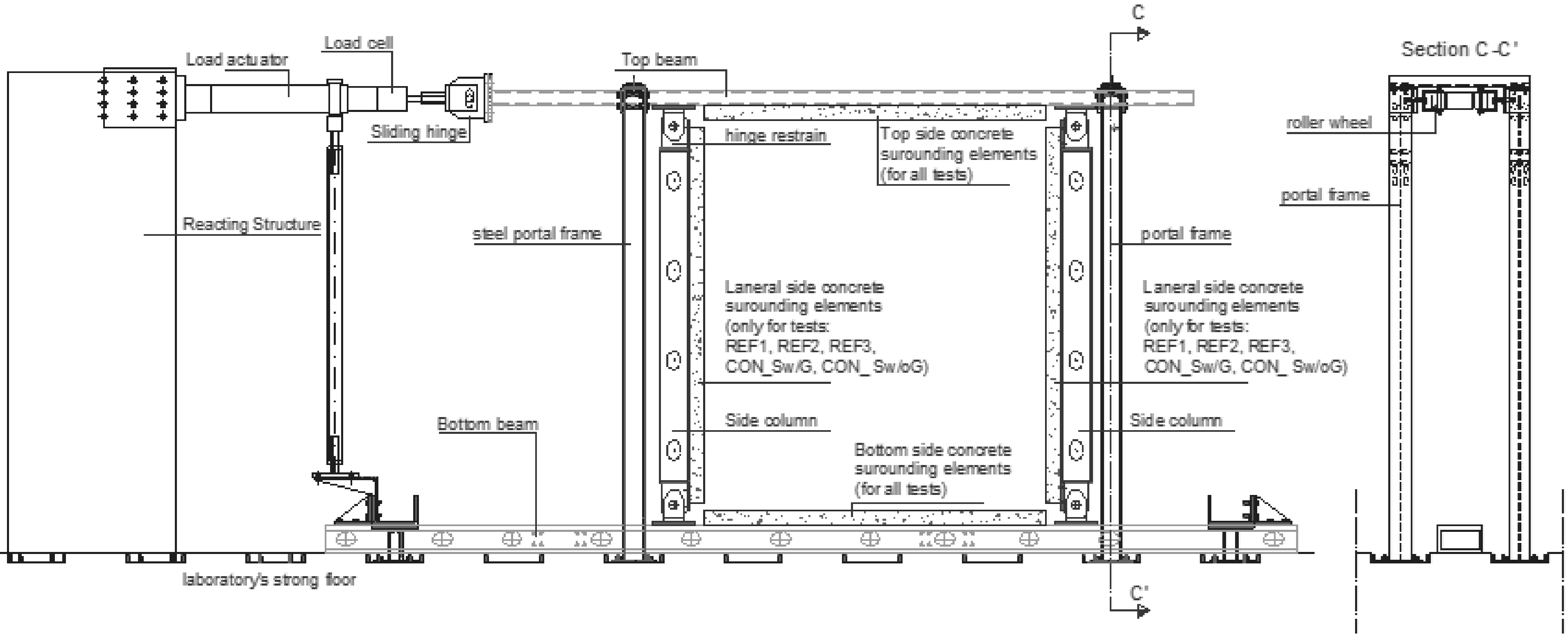




Top and bottom

Experimental programme – Test setup

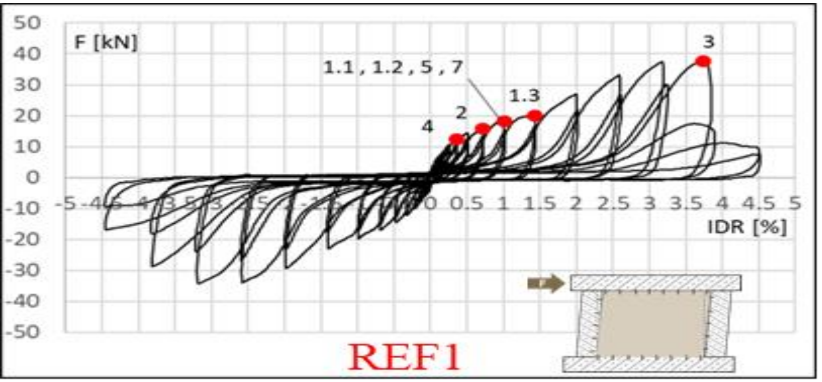
A specific steel frame for in-plane tests on non-structural walls was adopted as test **set-up**.

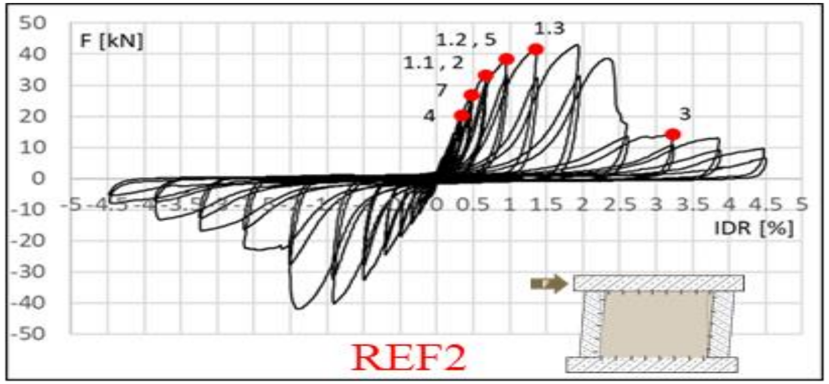


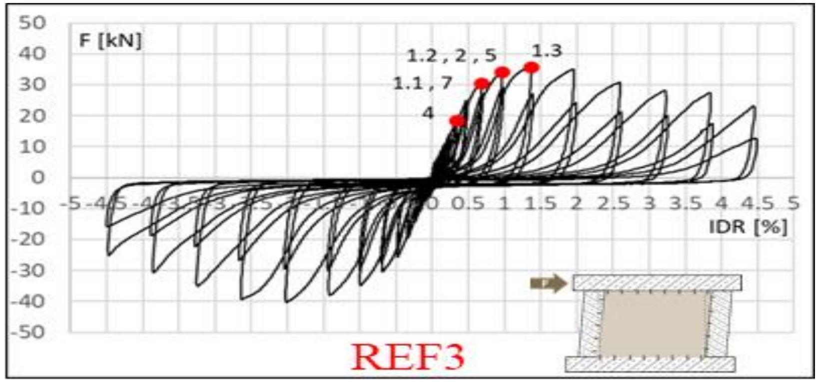
A *hydraulic load actuator* with *500 mm* stroke capacity and *500 kN* load capacity was used for the experimental activity.

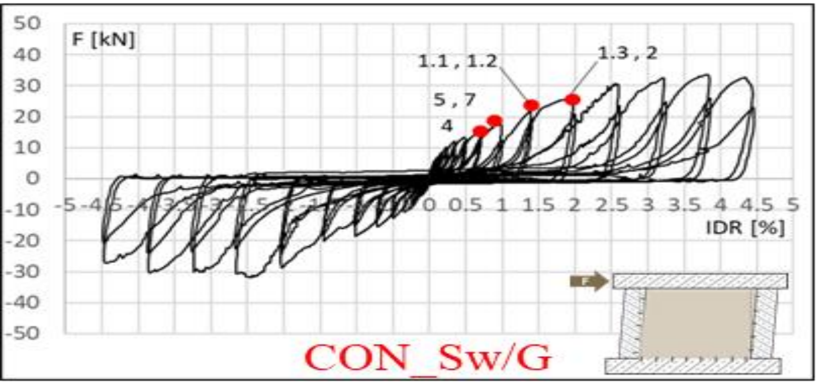
All **instrumentation** layouts included one *potentiometer* (P1) for measuring the wall top horizontal displacement and a variable number from 10 to 16 of *linear variable differential transducers (**LVDTs**)* to measure relative horizontal and vertical displacements.

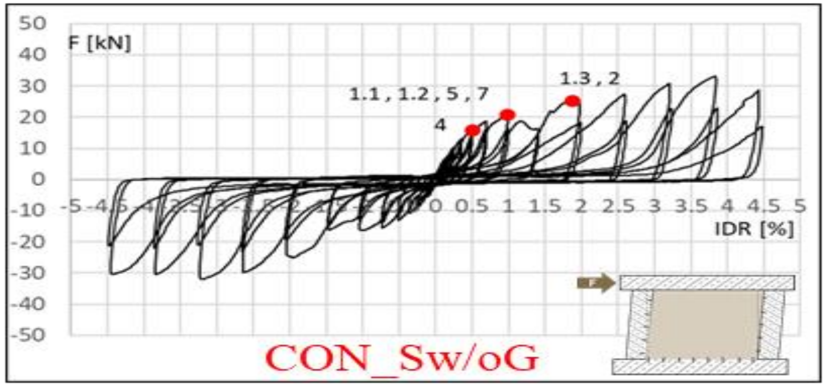
Experimental results - Load vs IDR curves

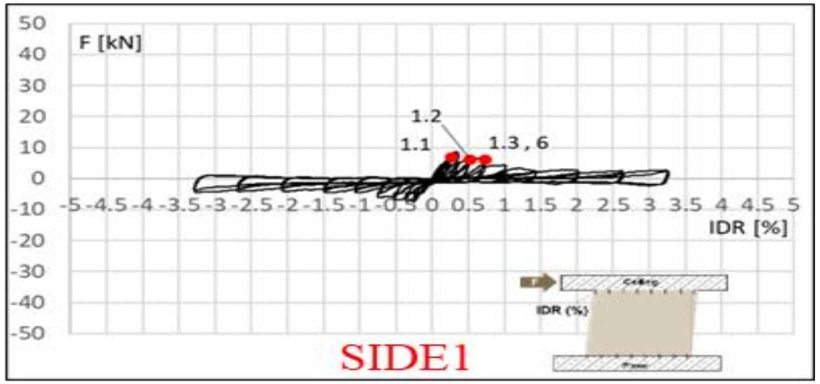


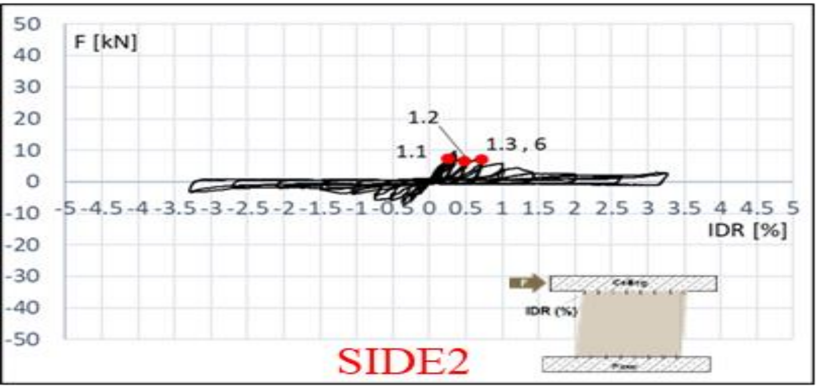












Specimens were characterised by a fully nonlinear, pinched hysteretic cyclic response.

Experimental results - Observed damage

1. *Rupture, crushing or spalling of panel portions*

2. *Crack in panel*

3. *Out-of-plane collapse of panels without falling down of panels*

4. *Screw tilting*

5. *Screw breaking on panel edge*

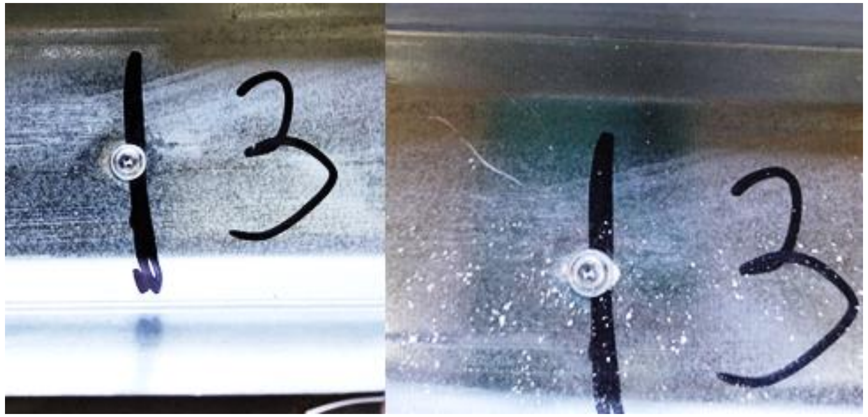
5. *Screw pull out/trough*

6. *Stud to track fixing failure*

7. *Gap opening between panel and structural elements*

Experimental results - Observed damage (PAFs)

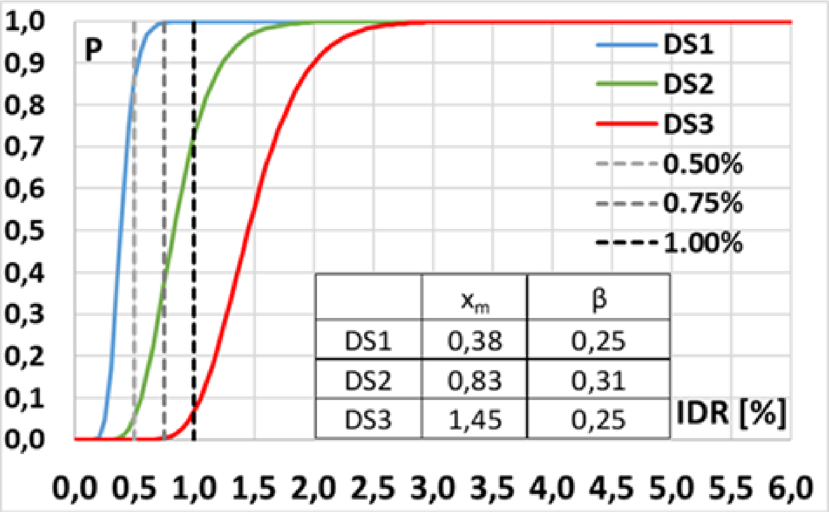
Before test After test

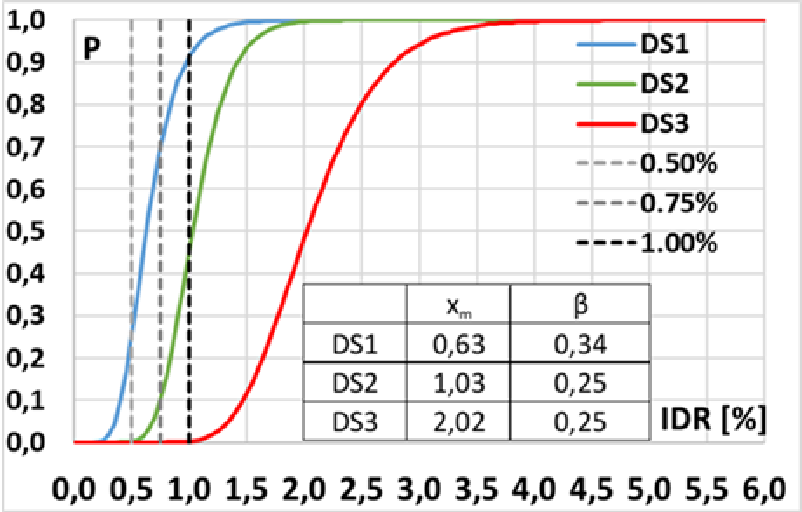


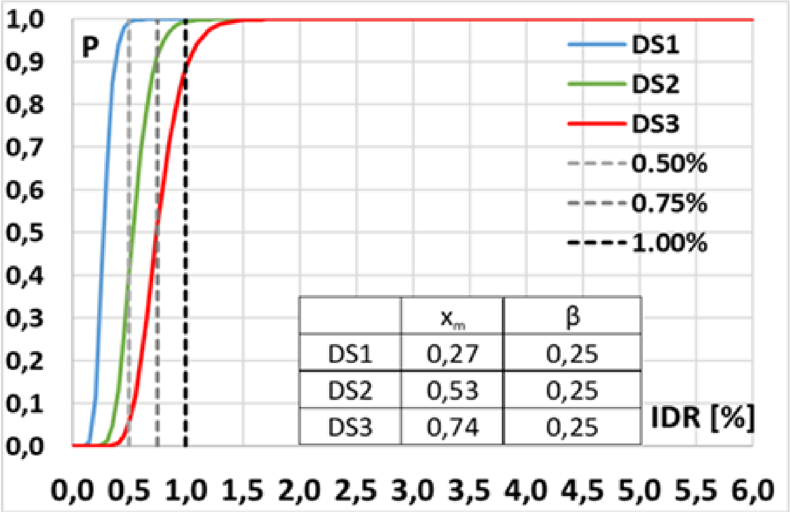
Before test After test

Note that no significant damage was observed related to PAFs connecting both studs and tracks to concrete surrounding elements, regardless of the used type of surrounding connection, type of sliding connection, or spacing of PAFs.

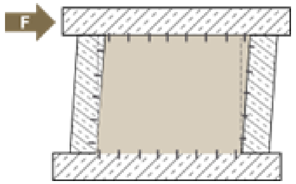
Experimental results – Fragility curves for partition walls



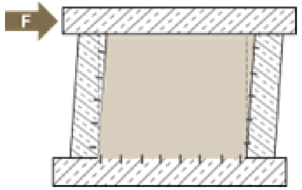




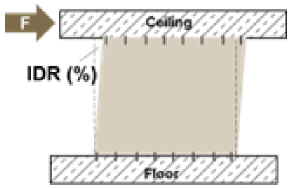
Configuration 1



Configuration 2



Configuration 3



	Probabilities of exceeding the limit of 0.50%			Probabilities of exceeding the limit of 0.75%			Probabilities of exceeding the limit of 1.00%		
	DS1	DS2	DS3	DS1	DS2	DS3	DS1	DS2	DS3
Configuration 1	0.86	0.06	0.00	1.00	0.38	0.00	1.00	0.73	0.07
Configuration 2	0.26	0.00	0.00	0.70	0.10	0.00	0.91	0.45	0.00
Configuration 3	0.99	0.41	0.06	1.00	0.92	0.52	1.00	0.99	0.89

	Probabilities of occurrence of 0.50%				Probabilities of occurrence of 0.75%				Probabilities of occurrence of 1.00%			
	NO DAM	DS1	DS2	DS3	NO DAM	DS1	DS2	DS3	NO DAM	DS1	DS2	DS3
Configuration 1	0.14	0.81	0.06	0.00	0.00	0.62	0.37	0.00	0.00	0.27	0.66	0.07
Configuration 2	0.74	0.25	0.00	0.00	0.30	0.60	0.10	0.00	0.09	0.46	0.45	0.00
Configuration 3	0.01	0.59	0.35	0.06	0.00	0.08	0.40	0.52	0.00	0.01	0.11	0.89

It can be observed that for all DSs the Configuration 2 shows the lower seismic fragility, the Configuration 3 exhibited the highest seismic fragility and the Configuration 1 has an intermediate seismic fragility.

Concluding remarks

1 Recent earthquakes have demonstrated that non-structural building elements including façades, partitions, and ceilings of a building can limit a building's ability to reopen for rapid occupation following an earthquake, resulting in significant economic losses

2 The study of the seismic response of non-structural building elements has received less attention in the past than that of structural systems, resulting in a lack of specified design guidelines for non-structural systems.

3 Traditional methods, such as thorough numerical simulations or analytical approaches, cannot easily tackle the problem of predicting the seismic response of non-structural building elements.

4 Recently many research teams have focused their attention on seismic response of non-structural building elements. In this context, many studies on the seismic behaviour of drywall non-structural building elements have been carried out at University of Naples Federico II.

5 Nowadays, the Seismic European code (Eurocode 8, EN 1998) have been reviewed with the aim to cope up with the gap between research, technology, and standards and solve the above-mentioned criticisms.

Thank you for your kind attention

X EDIZIONE SEISMIC ACADEMY

Think smart, build safe

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Progettazione sismica di elementi non strutturali: evoluzione normativa e avanzamenti della ricerca

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