

X EDIZIONE SEISMIC ACADEMY

Think smart, build safe

13 giugno 2023



Progettazione sismica di elementi non strutturali: evoluzione normativa e avanzamenti della ricerca Raffaele Landolfo, landolfo@unina.it Università di Napoli Federico II



PROGETTAZIONE SISMICA DI ELEMENTI NON STRUTTURALI Evoluzione normativa e avanzamenti della ricerca



- 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



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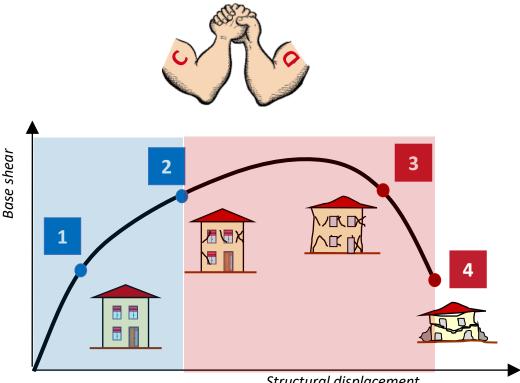
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Performance-Based Design

General approach



Structural displacement

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)

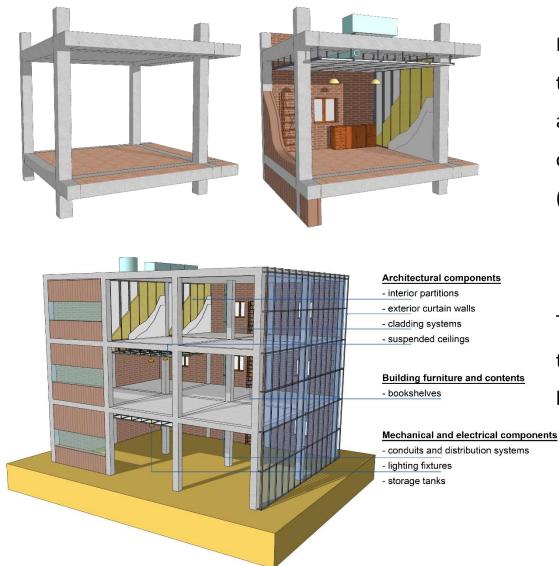
3. Life Safety:

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.

General definition



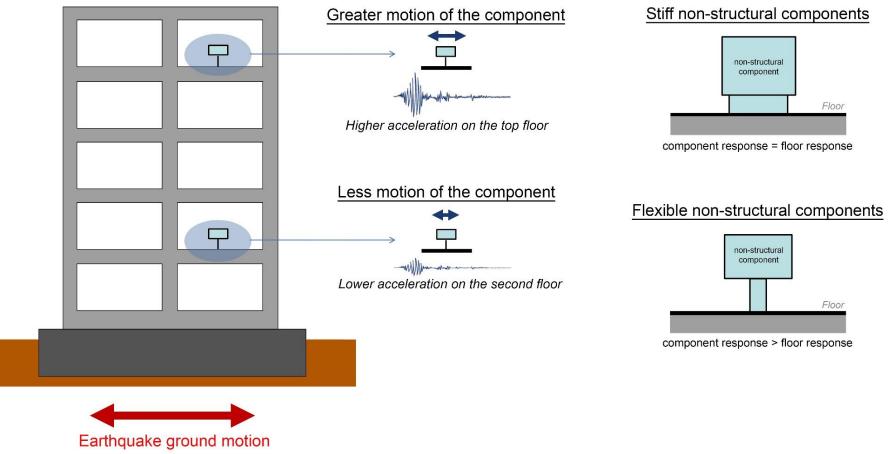
Non-structural components are defined as those systems and elements housed in or attached to a building, which are not part of the main load-bearing structural system (*Villaverde, 1997*)

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

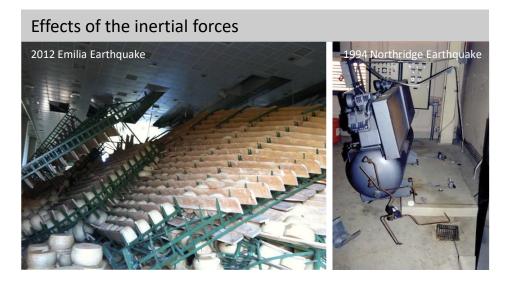


Reducing the Risks of Nonstructural Earthquake Damage – A Practical Guide

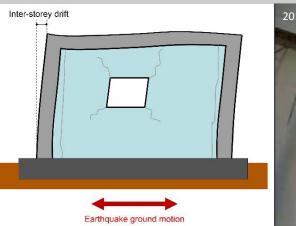
The seismic response of non-structural building components during an earthquake depends mainly on the component location within the building structure and on the component's dynamic characteristics



Seismic behaviour



Main causes of seismic damage





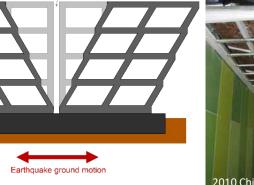
Effects of the interaction



Effects of the building deformation

Damage to non-structural components due to the building pounding

Effects of the building pounding

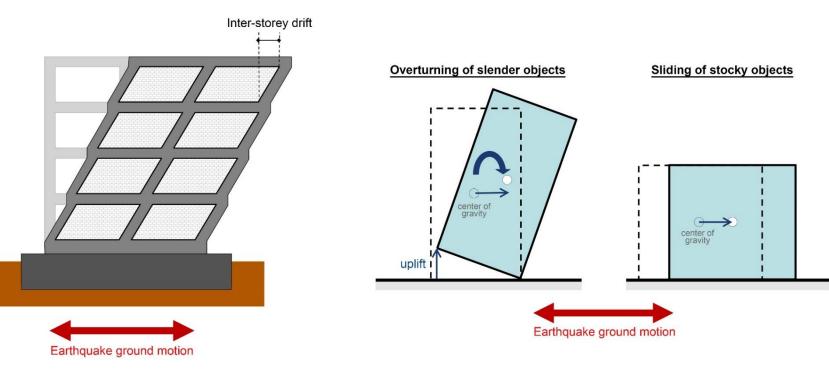




Seismic classification

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



Seismic classification

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	Р
Light	S	Р
Ceilings		
Directly applied to the building structure	Р	
Suspended gypsum board ceilings	Р	
Suspended acoustic lay-in tile ceilings	S	Р
P: Primary response; S: secondary response		



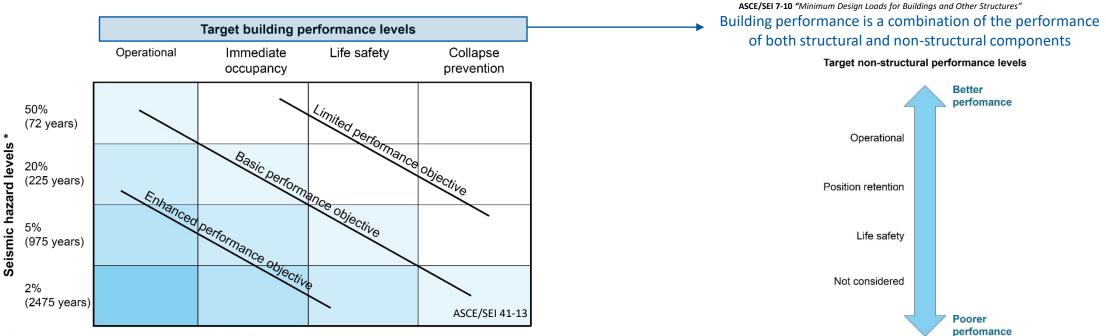


Performance-Based Design

Seismic Evaluatio and Retrofit of Existing Buildings

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"



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

. .	Target Non-structural Performance Levels			
Component group	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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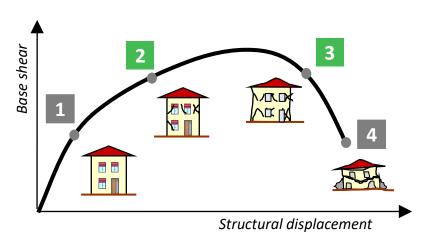
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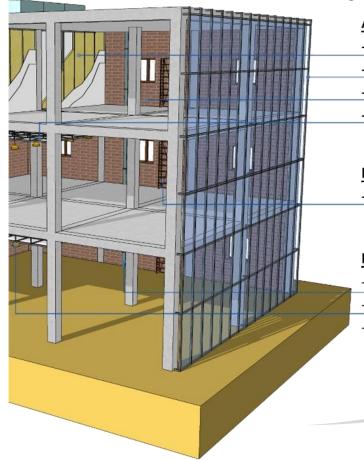
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General definitions and prescriptions



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

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

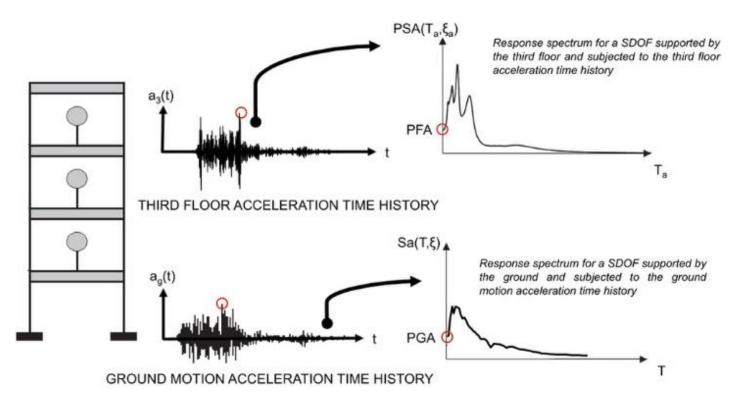
Non-structural elements of buildings that might, in case of failure, cause risks to persons or affect the main structure or services of critical facilities



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

General definitions and prescriptions

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. <u>https://doi.org/10.1002/eqe.3523</u>

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

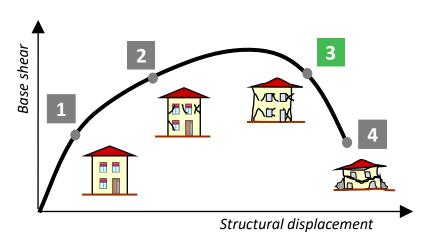
The structural system consequently will experience a certain pseudo-spectral acceleration.

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.

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05 91.120.25	Supersedes ENV 1998-1-1:1994, ENV 1998-1-2:1994, ENV 1998-1-3:1995	4.2.1	
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séismes - Partie 1: Règles générales, actions sismiques et	Tell 1: Grundlagen, Erdbebeneinwirkungen und Regeln für	4.2.5	Importan
règles pour les bâtiments	Hochbauten	4.3 \$	STRUCTURA
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standards may be obtained on application to the Central Secretariat o	r to any CEN member.	4.3.	
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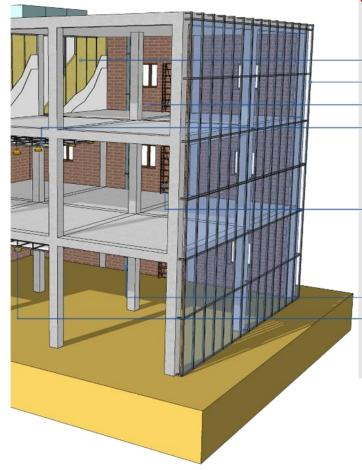
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General definitions and prescriptions



Non-structural elements

Architectural components

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

Building furniture and contents

- bookshelves

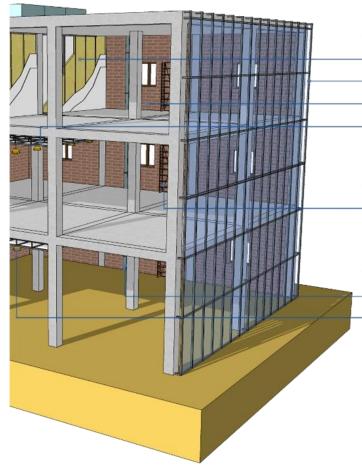
Mechanical and electrical components

- 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



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

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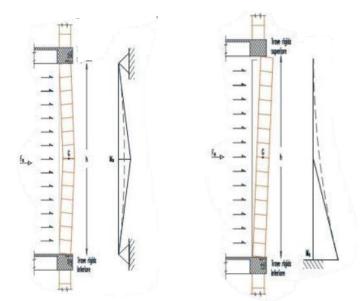
Level of performances LS of the structural system

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.



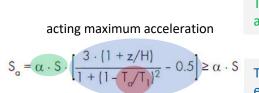
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Simplified procedure

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

Horizontal design seismic force

 $F_{a} = (S_{a} \cdot W_{a} \cdot \gamma_{a})/q_{a}$



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_{α} = fundamental vibration period of the non-structural component
- T₁ = fundamental vibration period of the building in the relevant direction Seismic Academy | 2023

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

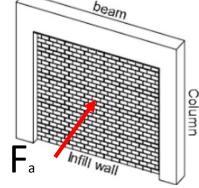
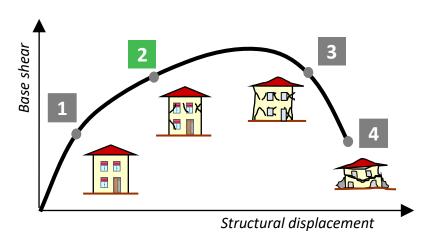


Table 4.4: Values of q_a for non-structural elements

Type of non-structural element	q_{a}
Cantilevering parapets or ornamentations	
Signs and billboards	1,0
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	2,0
Anchorage elements for permanent cabinets and book stacks supported by the floor	
Anchorage elements for false (suspended) ceilings and light fixtures	

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Part 1: General rules, seis	smic actions and rules fo	r buildings	4.2.3	
		Ŭ	4.2.3	
Eurocode 8: Calcul des structures pour leur résistance aux séismes - Partie 1: Règles générales, actions sismigues et	Eurocode 8: Auslegung	von Bauwerken gegen Erdbeben - bebeneinwirkungen und Regeln für	4.2.4	Combination coeffici
règles pour les bâtiments		Hochbauten	4.2.5	Importance classes as
				TRUCTURAL ANALYSIS
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Management Centre: P	ue ue olassari, 30 D-1000 DRUSSEIS			Damage limitation
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© 2004 CEN All rights of exploitation in any form and by any	y means reserved	Ref. No. EN 1998-1:2004: E	4.4.3	.2 Limitation of integral.
worldwide for OEL noticeal Uomhors				

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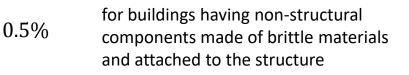
EN 1998-1

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



0.75% for buildings having ductile nonstructural components

1.0% for buildings having ductile nonstructural components fixed in a way so as not to interfere with structural deformations

- *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).
- v = 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

 $d_r \cdot v$

h

d, δ **F**₂ δ_{e2} h δ, F₁ δ_{e1} D_2 D,

Simplified procedure

PROGETTAZIONE SISMICA DI ELEMENTI NON STRUTTURALI Evoluzione normativa e avanzamenti della ricerca

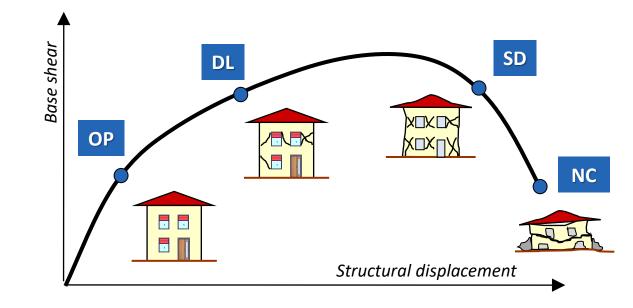


- Seismic design issues for nonstructural building elements
- Nonstructural building elements in the current Eurocode 8
- The new generation of Eurocode 8
- Nonstructural building elements in the new generation of Eurocodes
- Studies developed at University of Naples Federico II



X EDIZIONE SEISMIC ACADEMY 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 1 ST GENERATION	EN 1998 2 ND GENERATION
1 General rules and buildings	1-1 General rules
	1-2 Buildings
2 Bridges	2 Bridges
3 Existing buildings	3 Existing buildings and bridges
4 Silos, tanks and pipelines	4 Silos, tanks, pipelines, towers, masts and chimneys
5 Foundations and retaining structures	5 Foundation, retaining structures and Geotechnical aspects
6 Tower, masts and chimneys	



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

DL - Damage LimitationMost 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.

Damage severe, but structural collapse prevented. Nonstructural elements may fall. Repair generally not possible

NC - Near Collapse

The new generation of Eurocode 8

New definition of Limit states

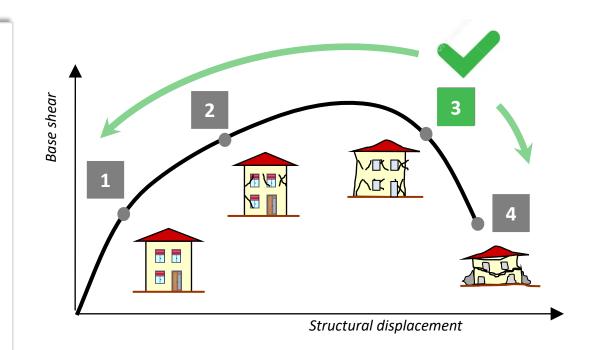
prEN 1998-1-1: Eurocode 8 — Design of structures for earthquake resistance —Part 1-1: General rules and seismic action

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.



Fully Operational (OP)
 Damage Limitation (DL)
 Significant Damage (SD)
 Collapse (NC)

PROGETTAZIONE SISMICA DI ELEMENTI NON STRUTTURALI Evoluzione normativa e avanzamenti della ricerca



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pr*EN* 1998-1-2

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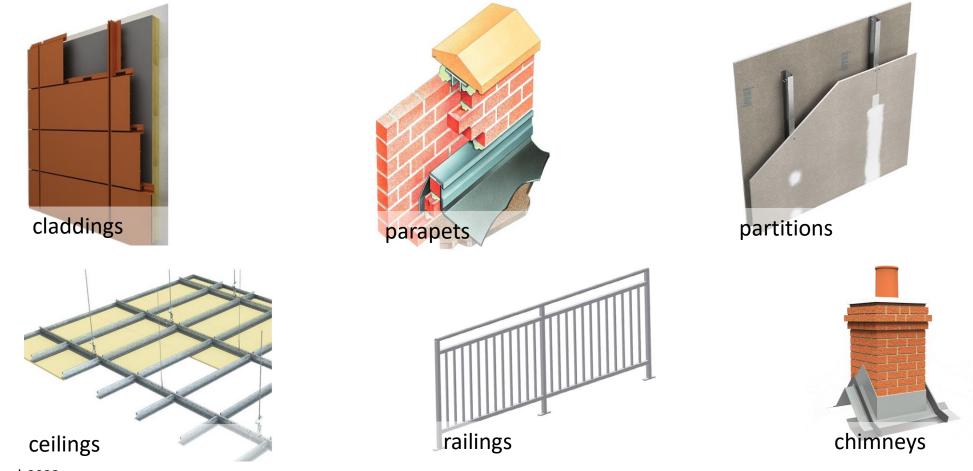
86

86

Terms and definitions

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.



Verification at SD limit state

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:

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

 $m_{\mbox{\tiny an}}$ is the mass of the element

San is the value in the floor acceleration spectrum determined for two horizontal directions

- $\gamma_{\mbox{\tiny an}}$ is the performance factor of the element
- q_{an}' is the period dependent behaviour factor of the ancillary element

Verification at SD limit state

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

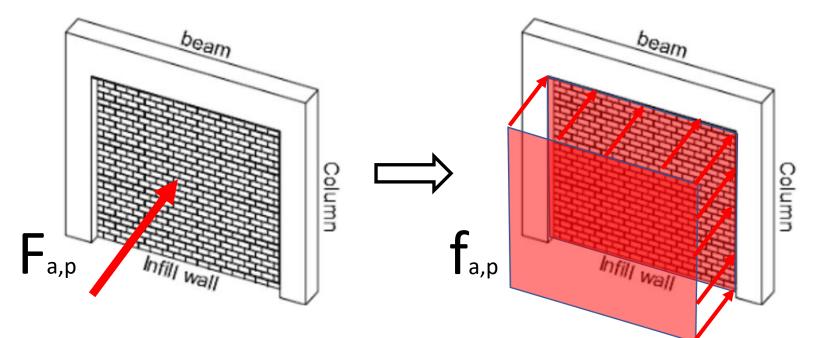
In case of ancillary elements with uniformly distributed mass (e.g. partition wall), the resultant force Fan may be distributed proportionally to the mass or its deformed shape.

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

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

 h_{P} is the length of the element;

 $\mathsf{I}_{\scriptscriptstyle \mathsf{P}}$ 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 yan is 1,0*
- For anchorage elements of machinery or for equipment participating to safety systems, the performance factor γ_{m} 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 $Table C.1 Maximum values of q_{an}$ 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	1
Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height	
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	2
Anchorage elements for permanent cabinets and book stacks supported by the floor	
Anchorage elements for false (suspended) ceilings and light fixtures	

Behaviour factor of the ancillary element

Verification at SD limit state

Verification at DL limit state

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

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

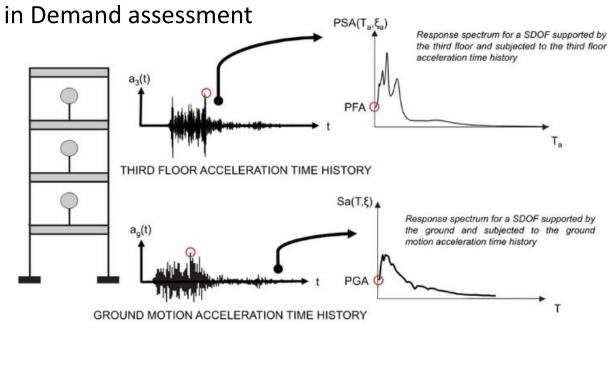
 $d_{r,\text{DL}}$ is the design interstorey drift calculated for the DL Limit state

h_s is the storey height

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

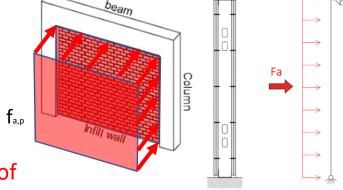
λ_{ns}	Type of ancillary elements
0,0025	for buildings having ancillary elements of unreinforced masonry units of Group 4 attached to the structure
0,0045	for buildings having ancillary elements of brittle materials attached to the structure, in particular unreinforced masonry with clay units of Groups 1, 2 or 3 with a thickness greater than 200 mm and the normalised mean compressive strength f₅≥ 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

Complexity



 Complexity in behaviour/capacity





The importance of seismic pre-qualification of non structural elements

PROGETTAZIONE SISMICA DI ELEMENTI NON STRUTTURALI Evoluzione normativa e avanzamenti della ricerca



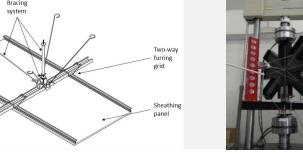
- Seismic design issues for nonstructural building elements
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- Research project
- Knauf Gips KG-UNINA Project, years 2012 2020
- Research project HILTI CORPORATION-UNINA Project, years 2020 - 2023





Suspended ceilings

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



DIST

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



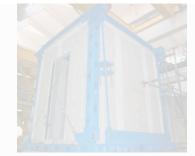
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Knauf Gips KG-UNINA Project



Bacing system Two-way grid sheathing panel





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



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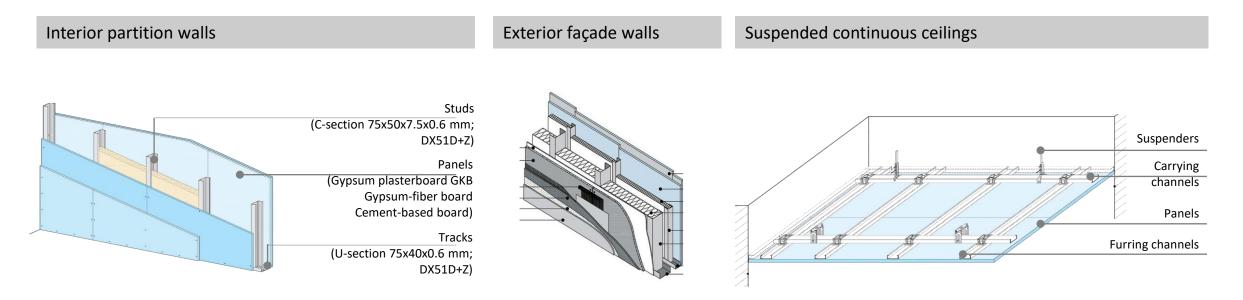
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Knauf Gips KG-UNINA Project

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.





Knauf Gips KG-UNINA Project

General experimental program











1	Test type	no. tests
	Steel material	12
Material and component	Self-tapping and self-drilling screws	42
tests	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		83 + 75 tests
suspended	Dynamic identification and	
ceilings sub-	earthquake tests	on 4 protoypes
systems		protoypes

Total no. of tests 349

Knauf Gips KG-UNINA Project

Tests on materials, components and connections

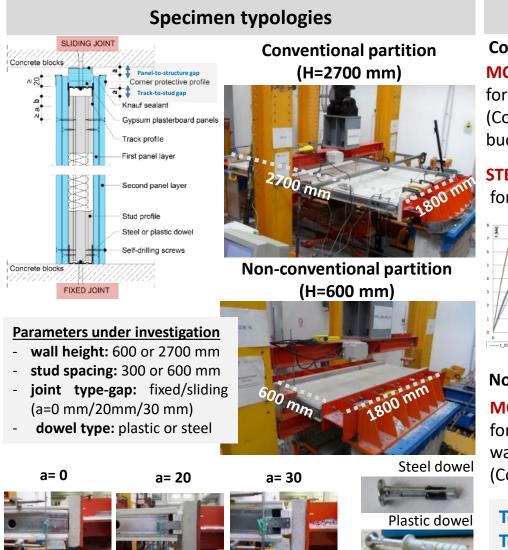
Since the response of lightweight steel gypsum board partition walls is strongly influenced by the local response of the different materials composing these systems, a large number of **tests on materials** and **components** was carried out in order to characterize their mechanical properties.



Knauf Gips KG-UNINA Project

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.**



Test program and main results

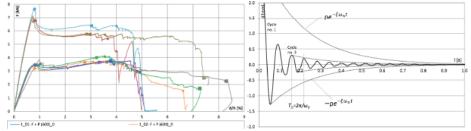
Conventional partition

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_q)



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)

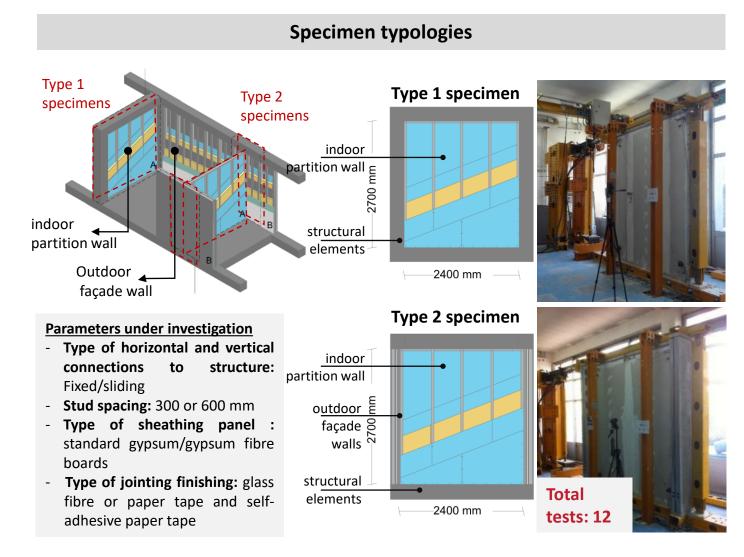
Total out-of-plane monotonic tests: 22 Total dynamic identification tests: 11

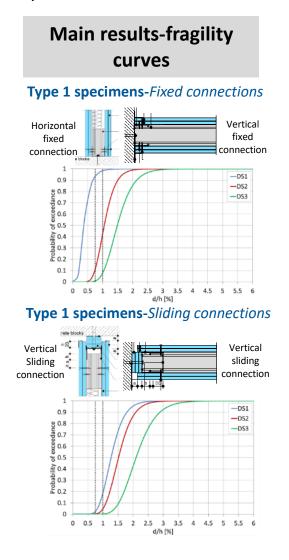
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Knauf Gips KG-UNINA Project

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.





Guerrasio-UNINA Project



Drywalls

• Research project

Knauf Gips KG-UNINA Project, years 2012 - 2020

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





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Bracing system Two-way furring Sheathing nane



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



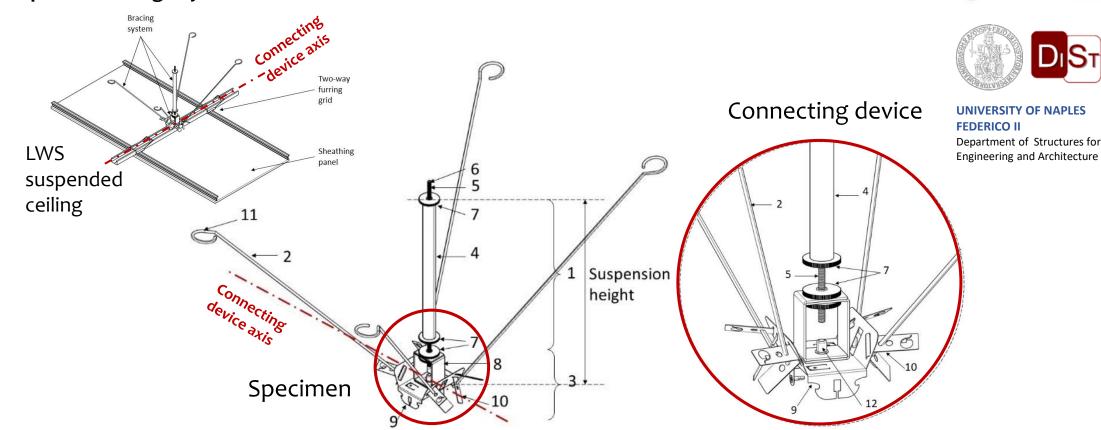
Whole building

• European research project ELISSA Project, years 2013-2016



Seismic Academy | 2023

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



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)

Guerrasio-UNINA Project

aucta/io

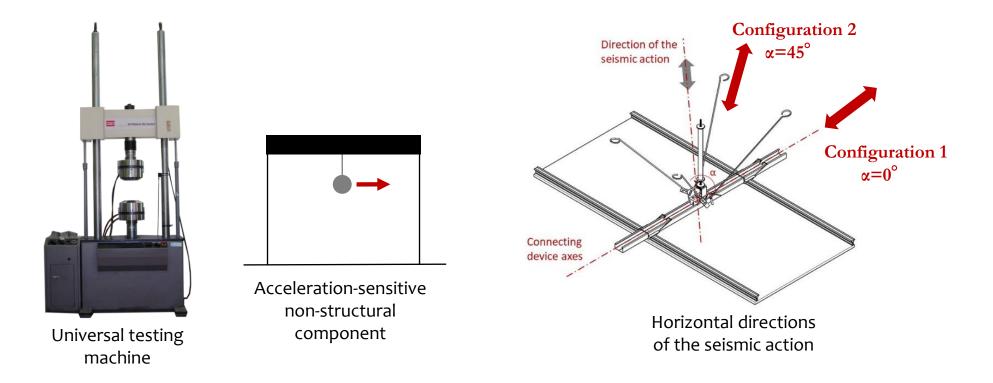
Guerrasio-UNINA Project

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

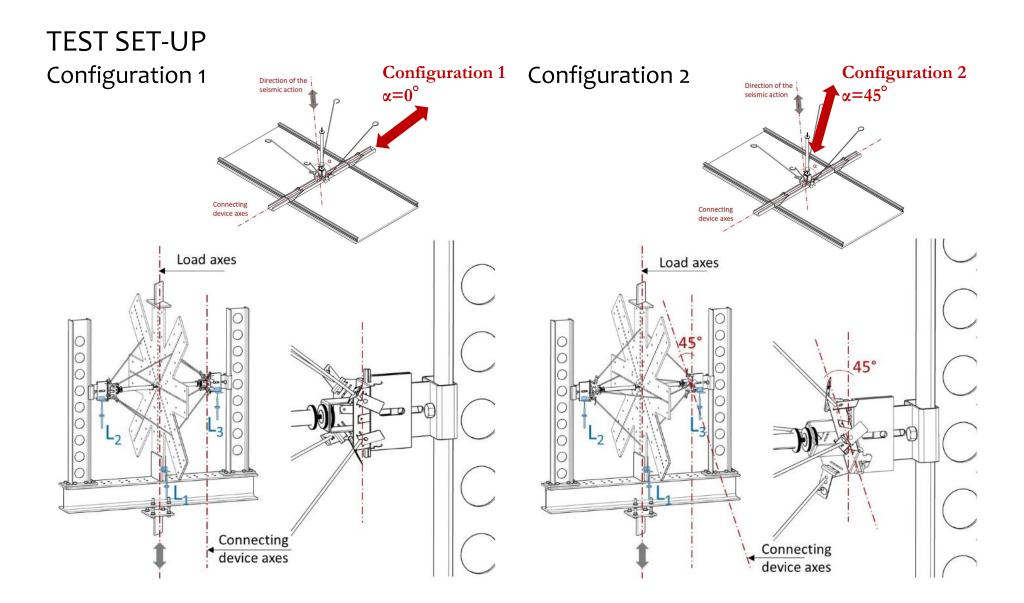
Basic assumptions:

(1) tests were carried out with a universal testing machine

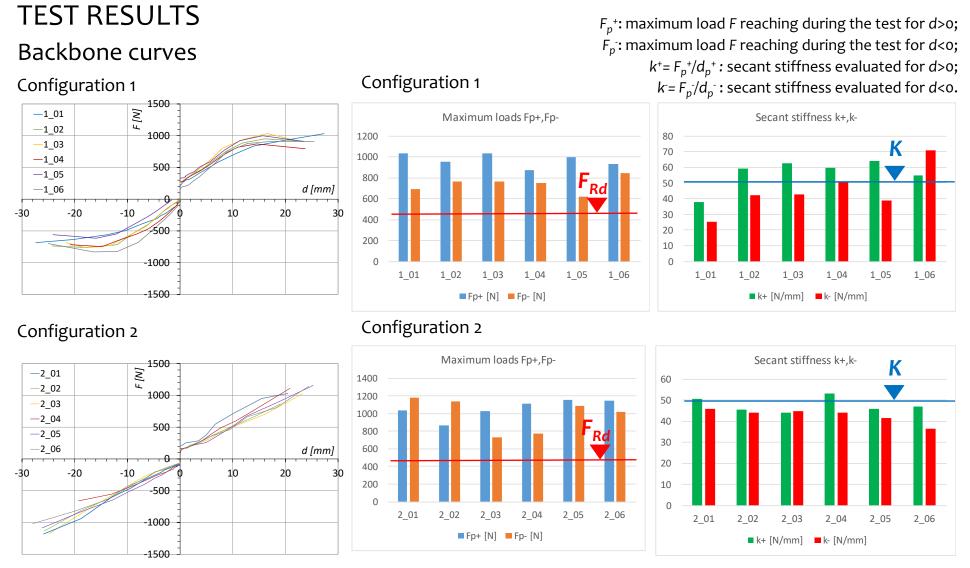
(2) tests were finalised to evaluate the behaviour of the bracing system considering the ceiling as an acceleration-sensitive non-structural component (3) the same test set-up was adopted for two different horizontal directions of the seismic action



Guerrasio-UNINA Project



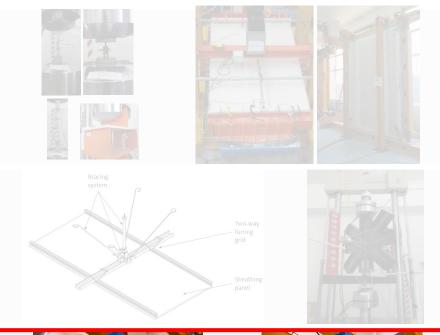
Guerrasio-UNINA Project



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

45

Knauf Gips KG-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

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Drywall and suspended ceilings sub-systems
Research project
Knauf Gips KG-UNINA Project, years 2012 - 2020



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Whole building

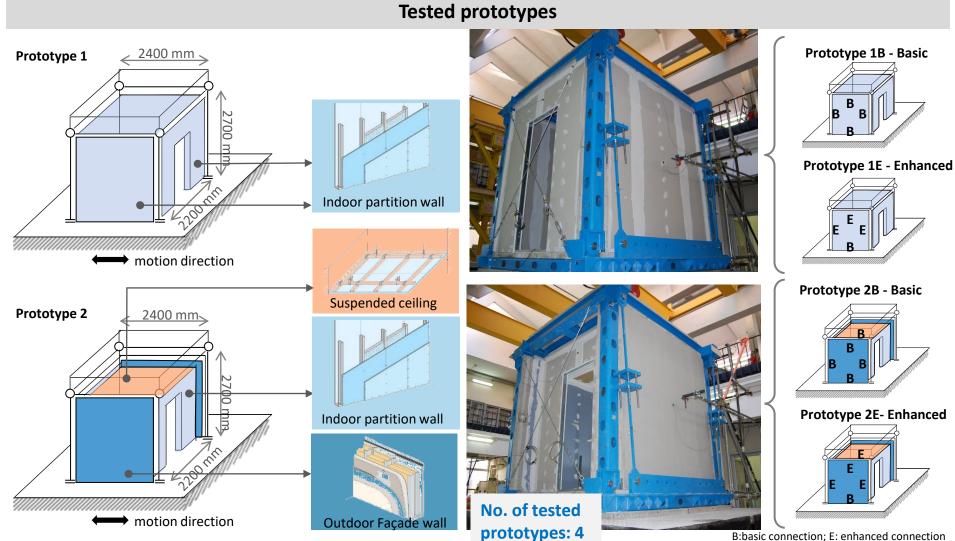
• European research project ELISSA Project, years 2013-2016



Knauf Gips KG-UNINA Project

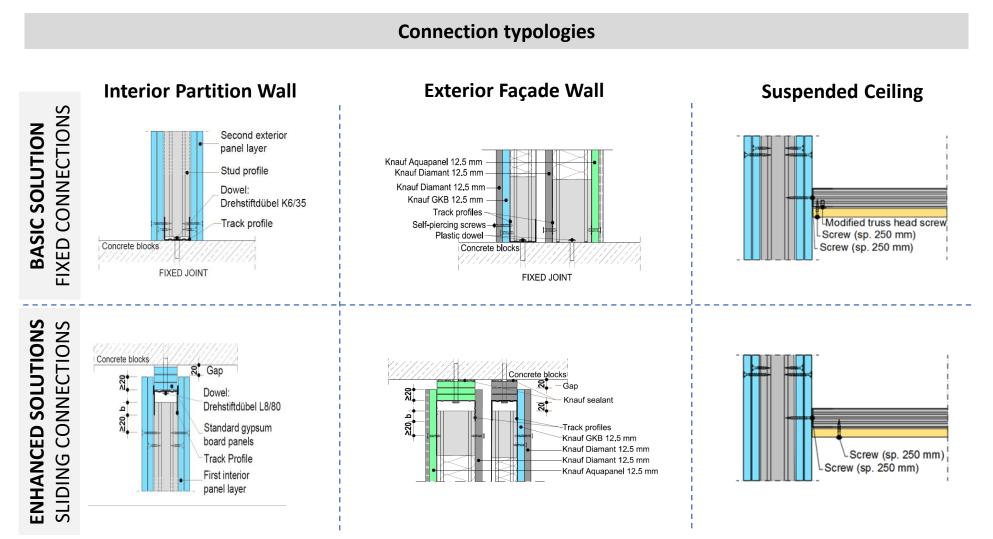
Drywall and suspended ceilings sub-systems: Shake table tests on partition walls, façade walls and suspended ceilings

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.



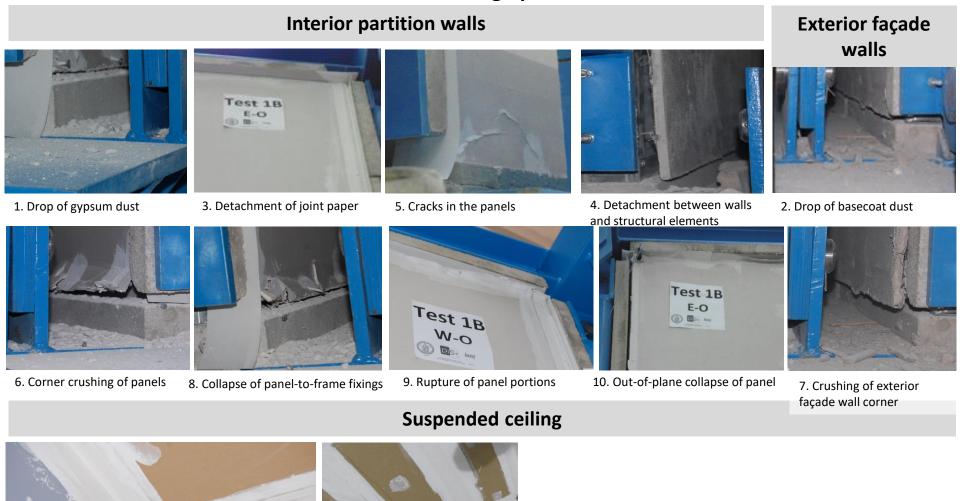
Knauf Gips KG-UNINA Project

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



Knauf Gips KG-UNINA Project

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



Very low damage observed for suspended ceiling

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Knauf Gips KG-UNINA Project

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

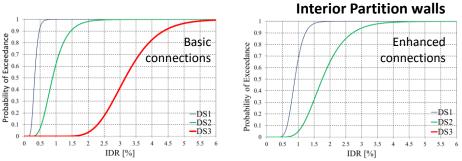
Observed damage phenomena	DS1	DS2	DS3
1. Drop of gypsum and/or plaster dust	•		
2. Detachment of joint tape	•		
3. Detachment between walls and surrounding structural elements		•	
4. Crack in panels		٠	
5. Corner crushing of panels		•	
6 Collapse of panel-to-frame fixings		•	
7. Rupture of panel portions			•
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

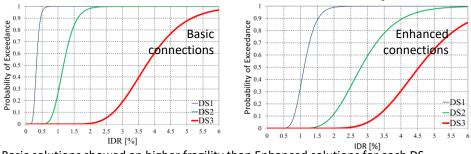
nit Interior Partition Walls			Damage limit	Exterior Façade Walls		
1_B-I	1_B-II	1_E	states	2 B	2 E	
Drift [%]	Drift [%]	Drift [%]		 Drift [%]	 Drift [%]	
0.32%	0.28%	0.89%	DS1	0.31	1.11	
0.66%	1.19%	1.39%	DS2	1.17	2.44	
3.12%	3.20%	-	DS3	3.74	4.54	
	1_B-I Drift [%] 0.32% 0.66%	1_B-I 1_B-II Drift [%] Drift [%] 0.32% 0.28% 0.66% 1.19%	1_B-I 1_B-II 1_E Drift [%] Drift [%] Drift [%] 0.32% 0.28% 0.89% 0.66% 1.19% 1.39%	1_B-I 1_B-II 1_E states Drift [%] Drift [%] Drift [%] DS1 0.32% 0.28% 0.89% DS1 0.66% 1.19% 1.39% DS2	1_B-I 1_B-II 1_E states 2_B Drift [%] Drift [%] Drift [%] Drift [%] Drift [%] 0.32% 0.28% 0.89% DS1 0.31 0.66% 1.19% 1.39% DS2 1.17	

Fragility curves



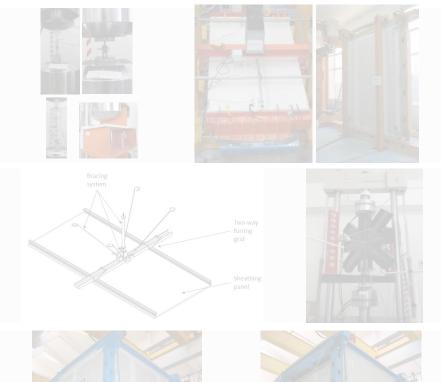
Interior Partition Walls showed an higher seismic fragility than Exterior Façade walls for each DS

Exterior Façade walls



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

ELISSA 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



ELISSA Project

ELISSA Project

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







ELISSA Research Project

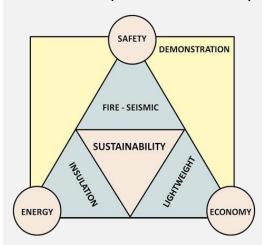
Energy Efficient Lightweight – Sustainable – SAfe – Steel Construction

PARTNERS



Project objective

The ELISSA project was devoted the development to and demonstration of nanoprefabricated enhanced lightweight Cold-Formed Steel (CFS) skeleton/dry wall constructions with improved of efficiency, fire energy 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

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

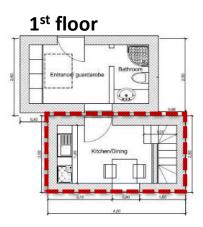


The case study: The "ELISSA house"

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).







"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 m² + terrace
- Total height: 5.4 m

The Elissa Mock-up



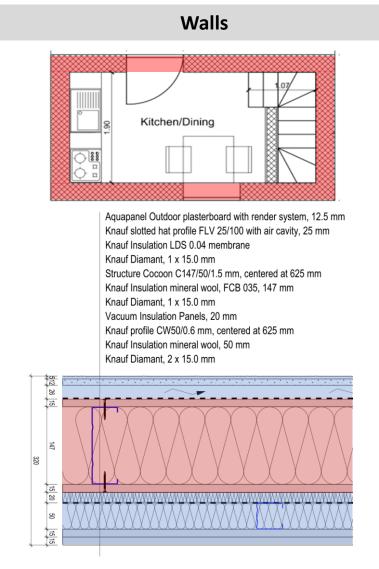


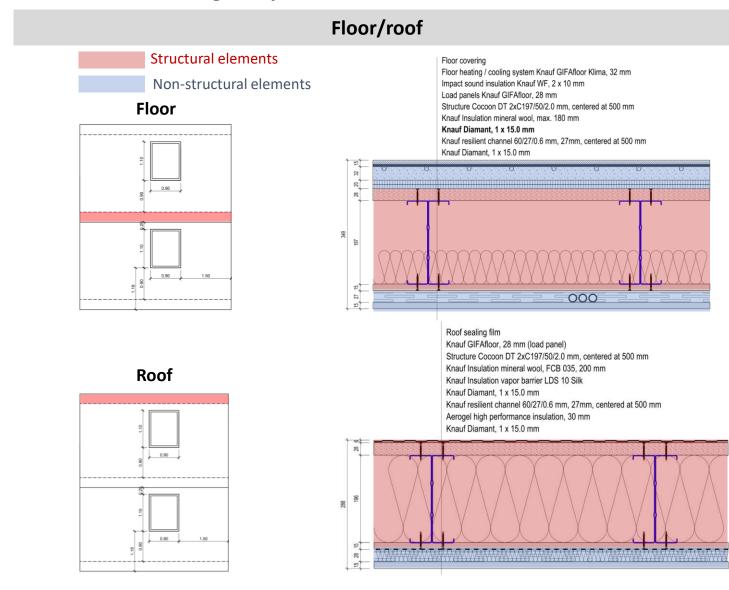
ELISSA MOCK-UP data

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

- Two storeys building
- Total gross area: 22.5 m²
- Total height: 5.4 m
- Weight of the complete building (w/ finishing) : 102 kN (4.53 kN/m²)
- Weight of the structural part (w/o finishing): 46 kN (2.04 kN/m²)

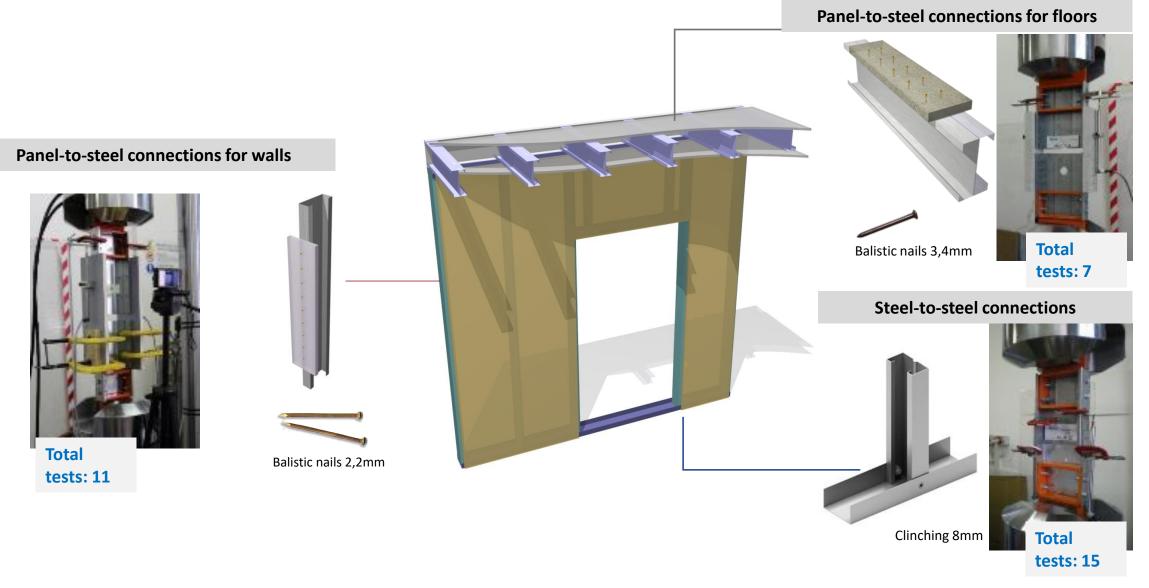
Structural and non-structural building components





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

Micro-Scale tests: shear tests on connections



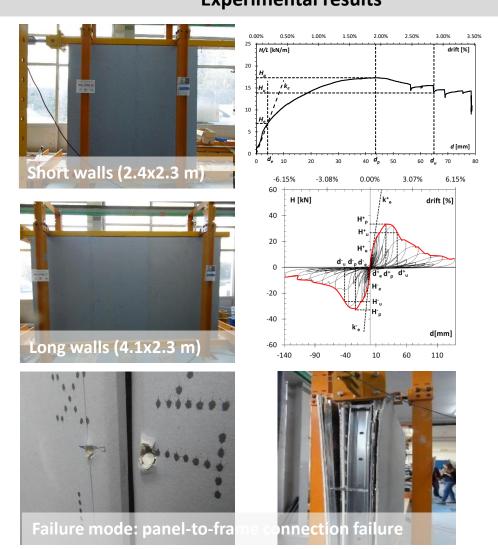
Specimen typologies and test program

Image: state with the state with th

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

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

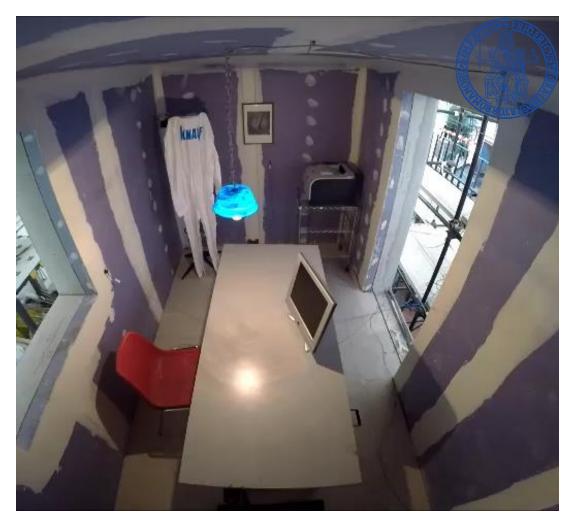
Elissa Mock-up configuration	Dynamic identification tests	Dynamic earthquake tests
Only Structure (Without finishing)	5 tests (0,05 – 0,10 g)	_
Complete construction (With finishing)	11 tests (0,05 – 0,10 g)	28 tests (5 – 150 % Scaling Factor)
Bare structure (without finishing)	Complete st	ructure (with finishing)
Exterior wall Walls and floors Whole bare struc panels nailing lifting		ior wall Whole complete structure Is fixing

External view

ELISSA Project

Earthquake test on shake table of the ELISSA mock-up

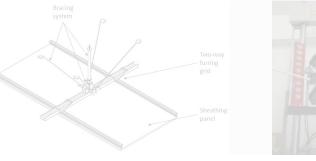
Internal view (2nd floor)



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

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



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HILTI CORPORATION-UNINA Project

Research objectives

Investigate the global seismic response of fullscale 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

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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).

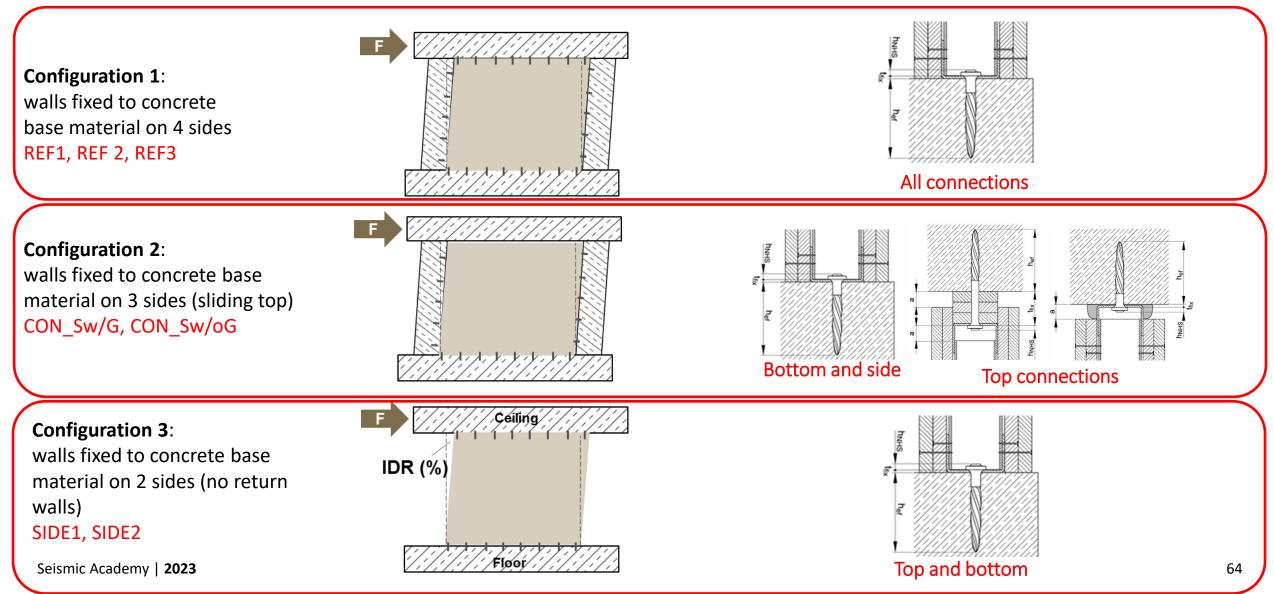




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Experimental programme - Test configurations

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



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Experimental programme – Test setup

Load cel Section C -C Load actuator Top beam roller wheel Slidina hinae op side concrete hinge restrain surounding elements for all tests) portal frame Reacting Structure steel portal frame portal frame Laneral side concrete aneral side concrete surounding elements suro unding elements only for tests: (only for tests: REF1, REF2, REF3, REF1, REF2, REF3, CON Sw/G, CON Sw/oG) CON Sw/G, CON Sw/oG) Side column Sid e column Bottom beam Bottom side concrete surounding elements for all tests laboratory's strong foor

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

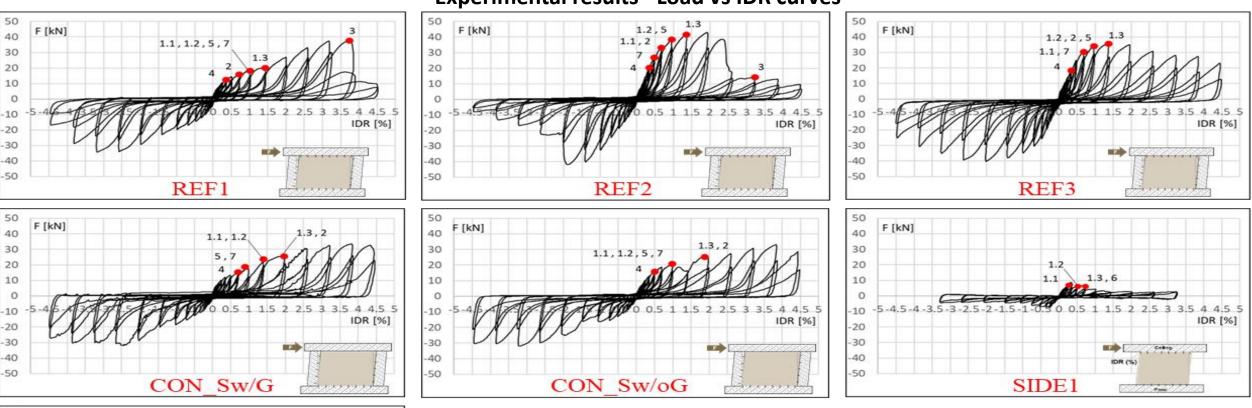
All **instrumentation** layouts included one *potentiometer* (P1) for measuring the wall top horizontal displacement and a variable number from 10 to 16 of *linear variable differential transducers* (*LVDTs*) to measure relative horizontal and vertical displacements.

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

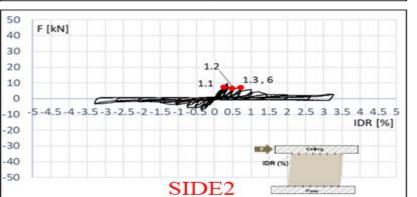


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Experimental results - Load vs IDR curves



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

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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 Seismic Academy | 2023



5. Screw breaking on panel edge



5. *Screw pull out/trough*



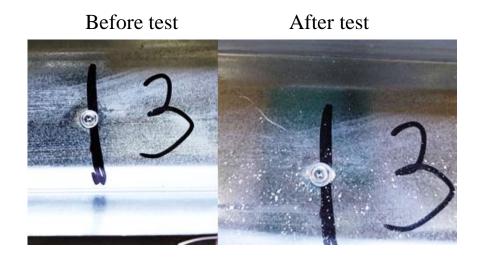
6. Stud to track fixing failure

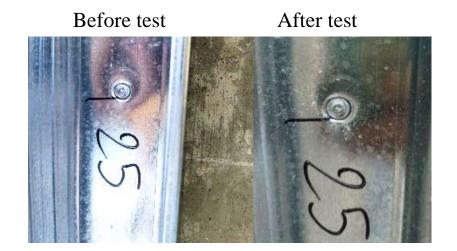


7. Gap opening between panel and structural elements

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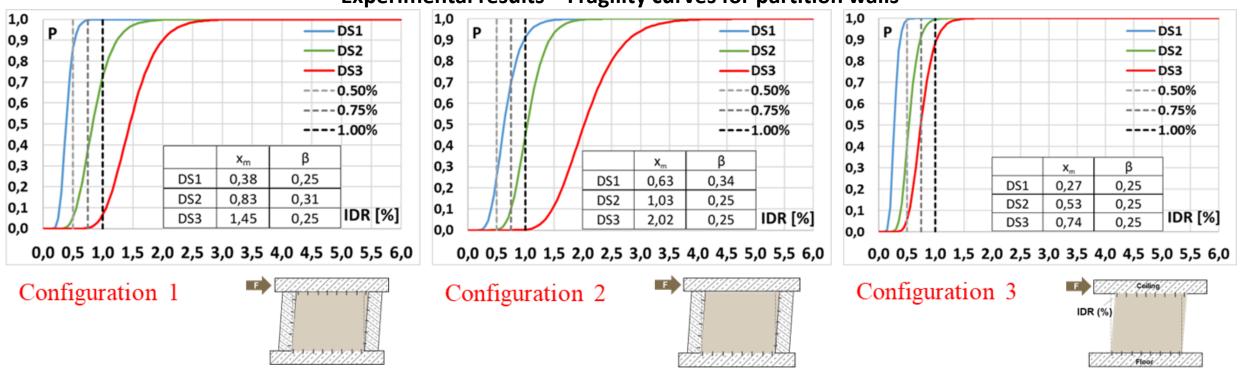
Experimental results - Observed damage (PAFs)





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.

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Experimental results – Fragility curves for partition walls

	Probabilities of exceeding the limit of 0.50%				linities of executive of the second s	0	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

- 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.
- A 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.



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Think smart, build safe

13 giugno 2023

Thank you for your kind attention

Progettazione sismica di elementi non strutturali: evoluzione normativa e avanzamenti della ricerca Raffaele Landolfo, Iandolfo@unina.it Università di Napoli Federico II

