Università di Napoli Federico II

Dipartimento di Strutture per l'Ingegneria e l'Architettura

Comportamento sismico di strutture leggere in acciaio

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Evento HILTI
Unicredit Pavilion,
Piazza Gae Aulenti 10, Milano

24 ottobre 2017

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2. Seismic design of CFS Constructions

3. Researches at the University of Naples Federico II

4. Case study

5. Concluding Remarks

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1. Introduction

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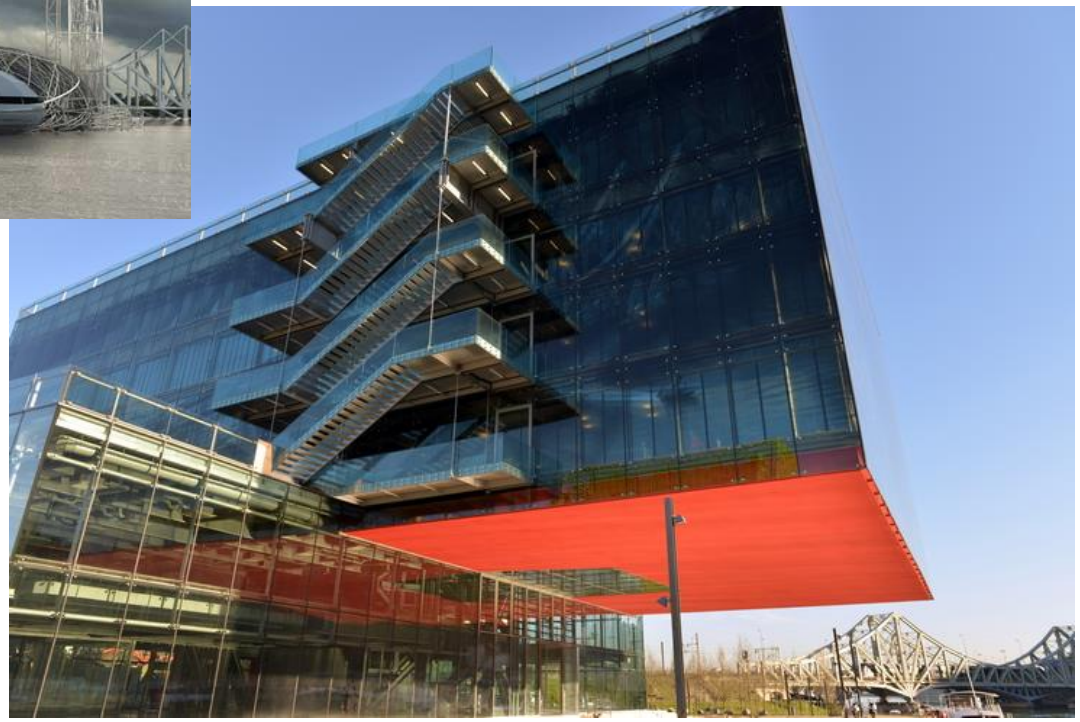
Steel structures are usually lightweight constructions

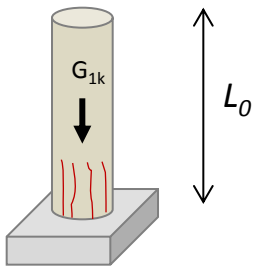


Odile Decq Architect. The *"Pavilion 8"* in Lyon, France, 2008

The lightweight of steel structures is due to the high structural efficiency offered by steel material

$$L_0 = \frac{f_d}{\gamma}$$

Specific strength or strength-to-weight ratio of materials (m)

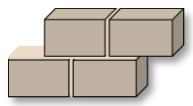
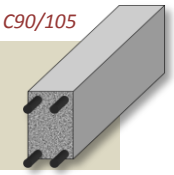
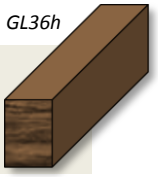
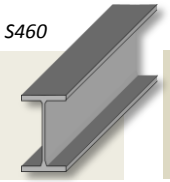


free breaking length or self-support length

N.B. L_0 is the maximum length of a vertical column of the material (assuming a fixed cross-section) that could suspend its own weight when supported only at the top.

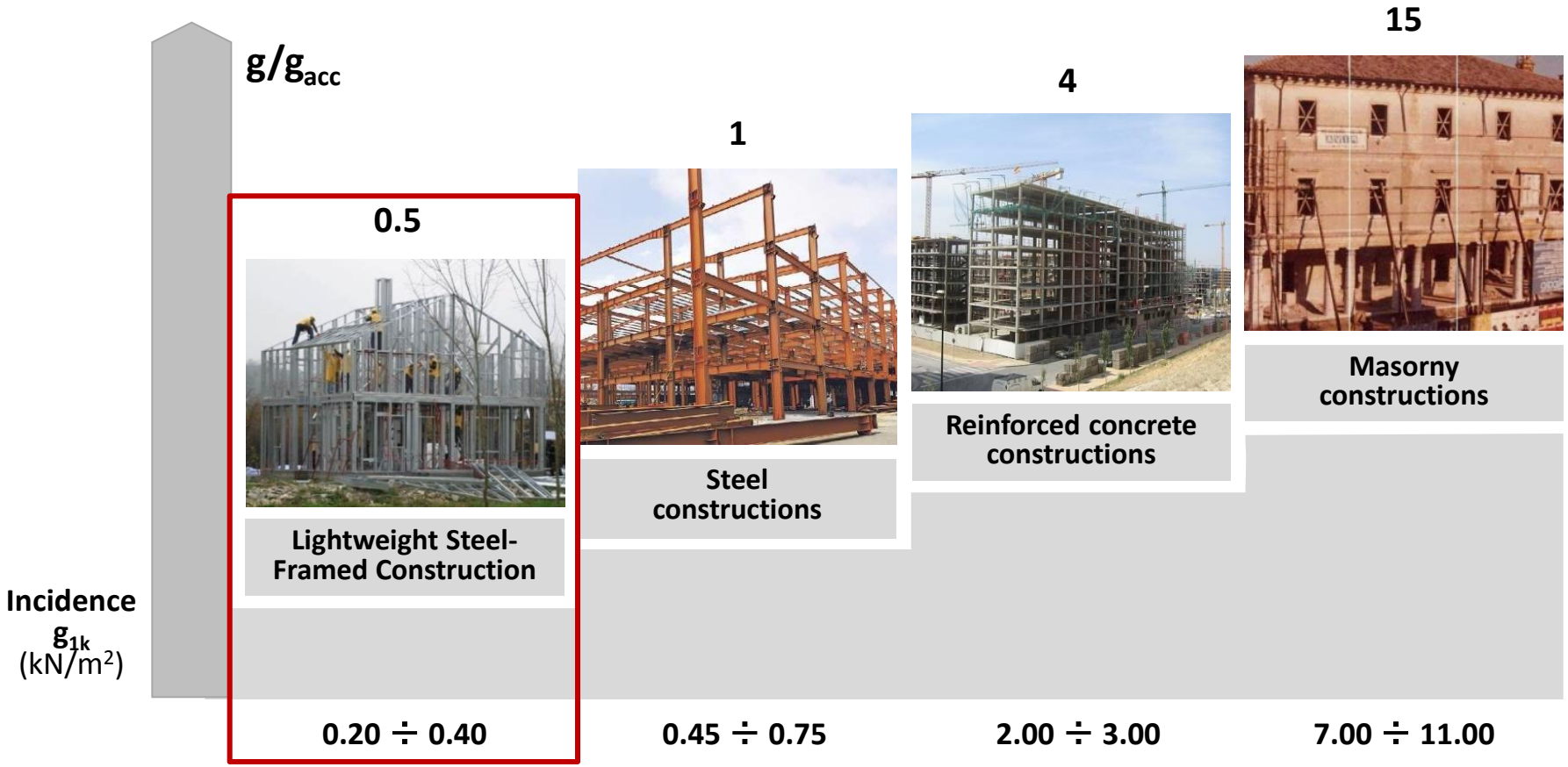
CONSTRUCTION MATERIALS

- **300** — Masonry — *M15; f_{bk}40*
- **1000** / *2500* — Ordinary reinforced-concrete NSC — *C40/50*; High-strength reinforced concrete HPC — *C90/105*
- **3800** — Wood — *GL36h*
- **5500** / *11000* — Steel — *S460*, *S960*

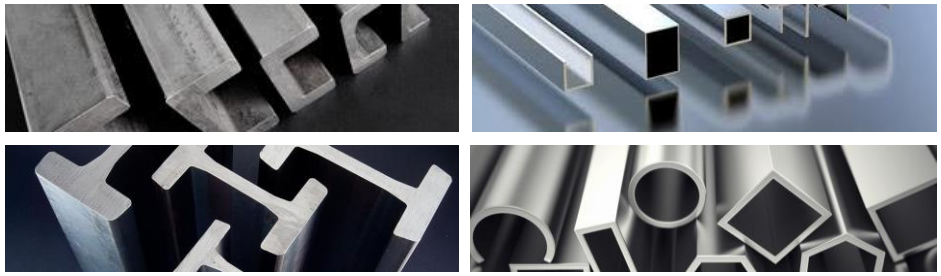
Lightweight Steel-Framed Construction using Cold-Formed Steel (CFS) profiles are inherently lightweight

Comparison between the weight incidences per unit area for different structural skeletons



The lightweight nature of these systems is due to the use of Cold-Formed Steel profiles

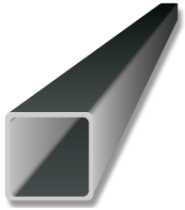
Hot-rolled profiles



IPE

RHS

HE



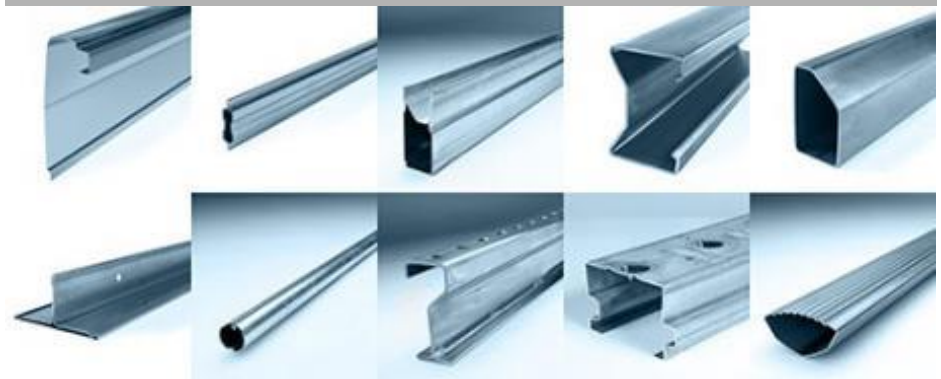
SHS

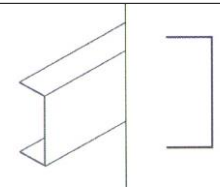
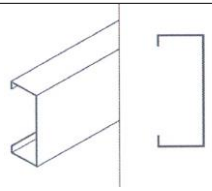
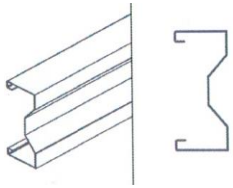
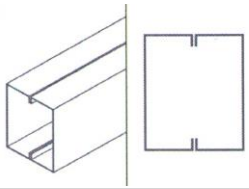
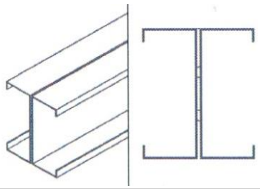
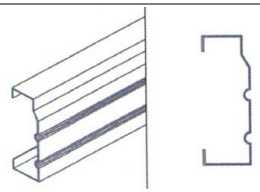
UPE/UPN

OHS

4 mm ≤ t ≤ 40 ÷ 45 mm

Cold-formed steel profiles



Unlipped channel section (U-section)	Lipped channel section (C-section)	Multibeam section
		
Box-section (obtained by double C-sections)	**I-section (obtained by double C-sections)**	**SFS section (Steel framing system)**
		

0 mm < t ≤ 3 mm

Reference codes for CFS profiles

- **CEN (2006), EN 1993-1-3**, *Eurocode 3: Design of steel structures – Part 1-3: General rules - Supplementary rules for cold formed thin gauge members and sheeting*. European Committee for Standardization, Bruxelles, 2006.

- **CEN (2006), EN 1993-1-5**, *Eurocode 3: Design of steel structures - Part 1-5: Plated structural elements.* European Committee for Standardization, Bruxelles, 2006.

- **CEN (2003), EN 1998-1,** *Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings.* European Committee for Standardization, Bruxelles, 2003.

Reference seismic codes for structural applications

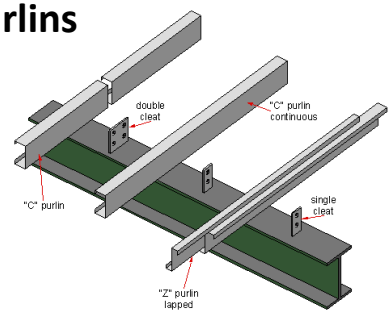
- **AISI (2015), AISI S400-15,** *North American Standard for Seismic Design of Cold-Formed Steel Structural Systems.* AISI (American Iron and Steel Institute), Washington, DC, 2016.

- **ASCE/SEI (2010), ASCE 7-10,** *Minimum design loads for buildings and other structures.* American Society of Civil Engineers, Reston, Virginia, 2010.

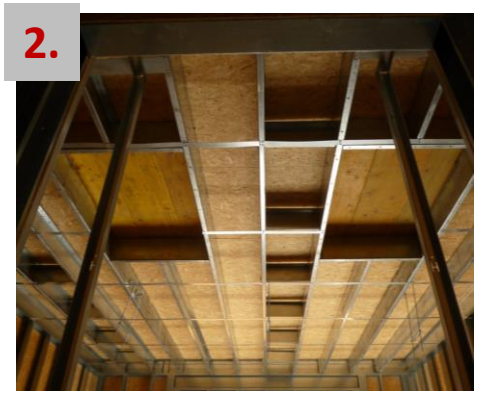
Structural applications

1.

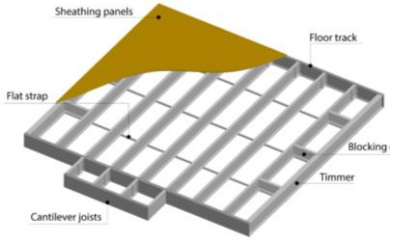
Purlins



2.

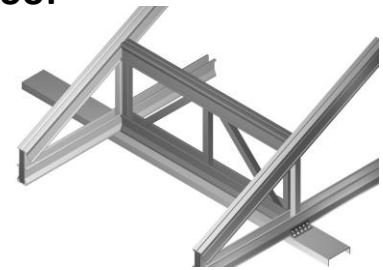


Floors



3.

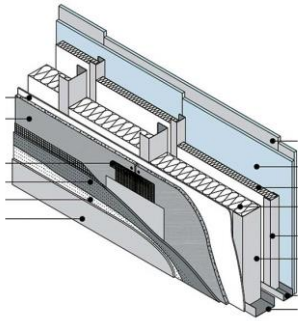
Roof



Non-structural applications

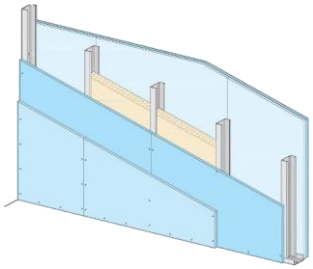
4.

Exterior façades



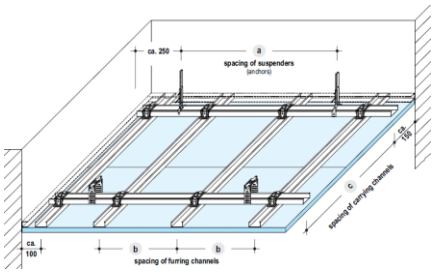
5.

Partition walls



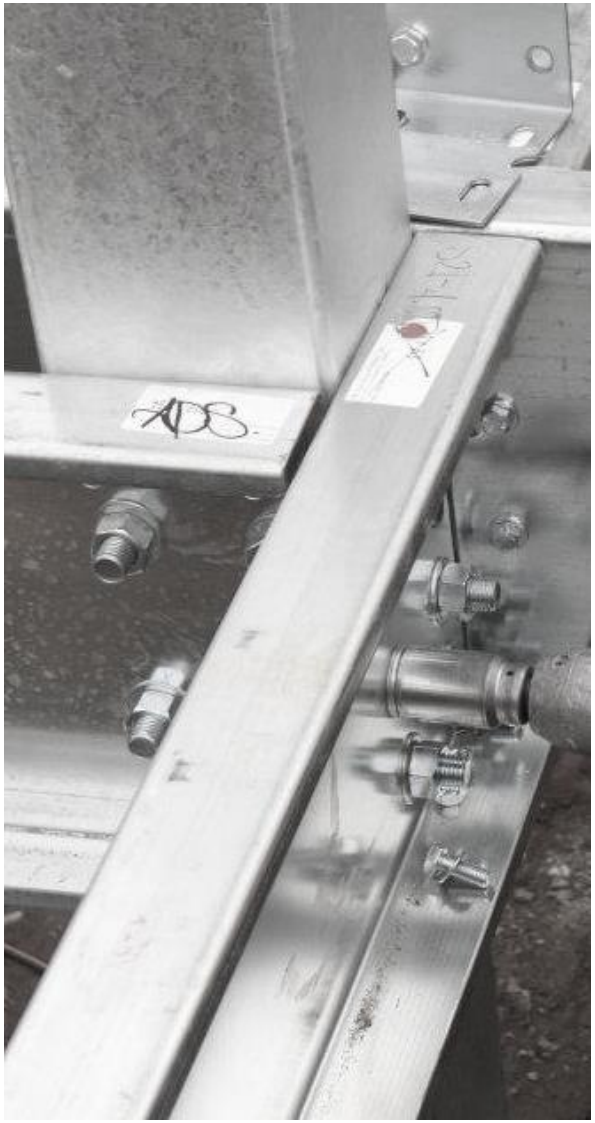
6.

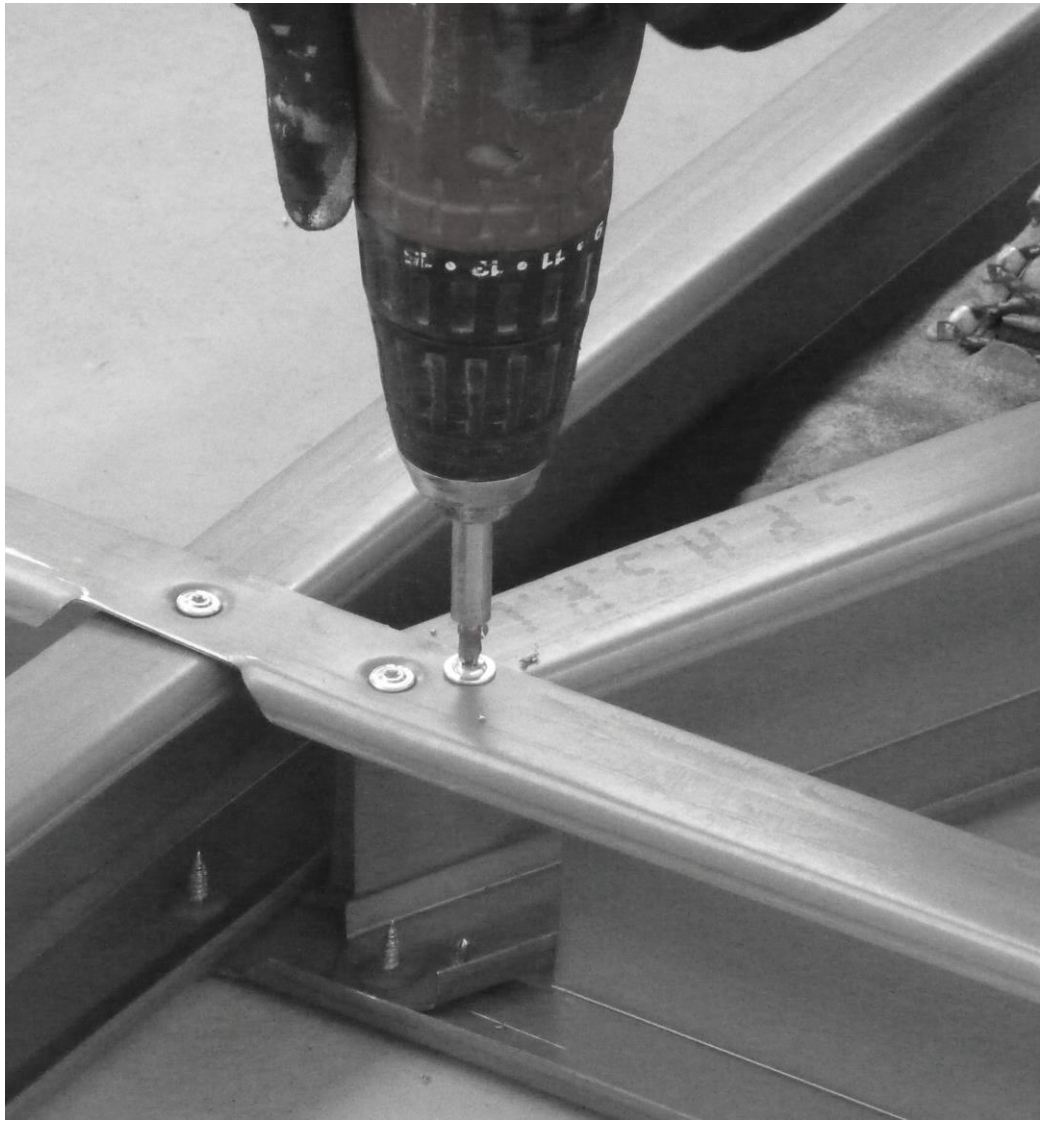
Suspended ceilings



Main advantages in using Lightweight Steel-Framed constructions

Technological issues: fastening systems





Technological issues: fastening systems

Mechanical fasteners

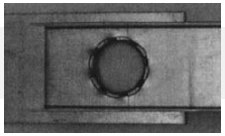
SCREWS

NAILS

BOLTS

BLIND RIVETS

SPECIAL MECHANICAL FASTENERS



Welding

Adhesives

Anchors

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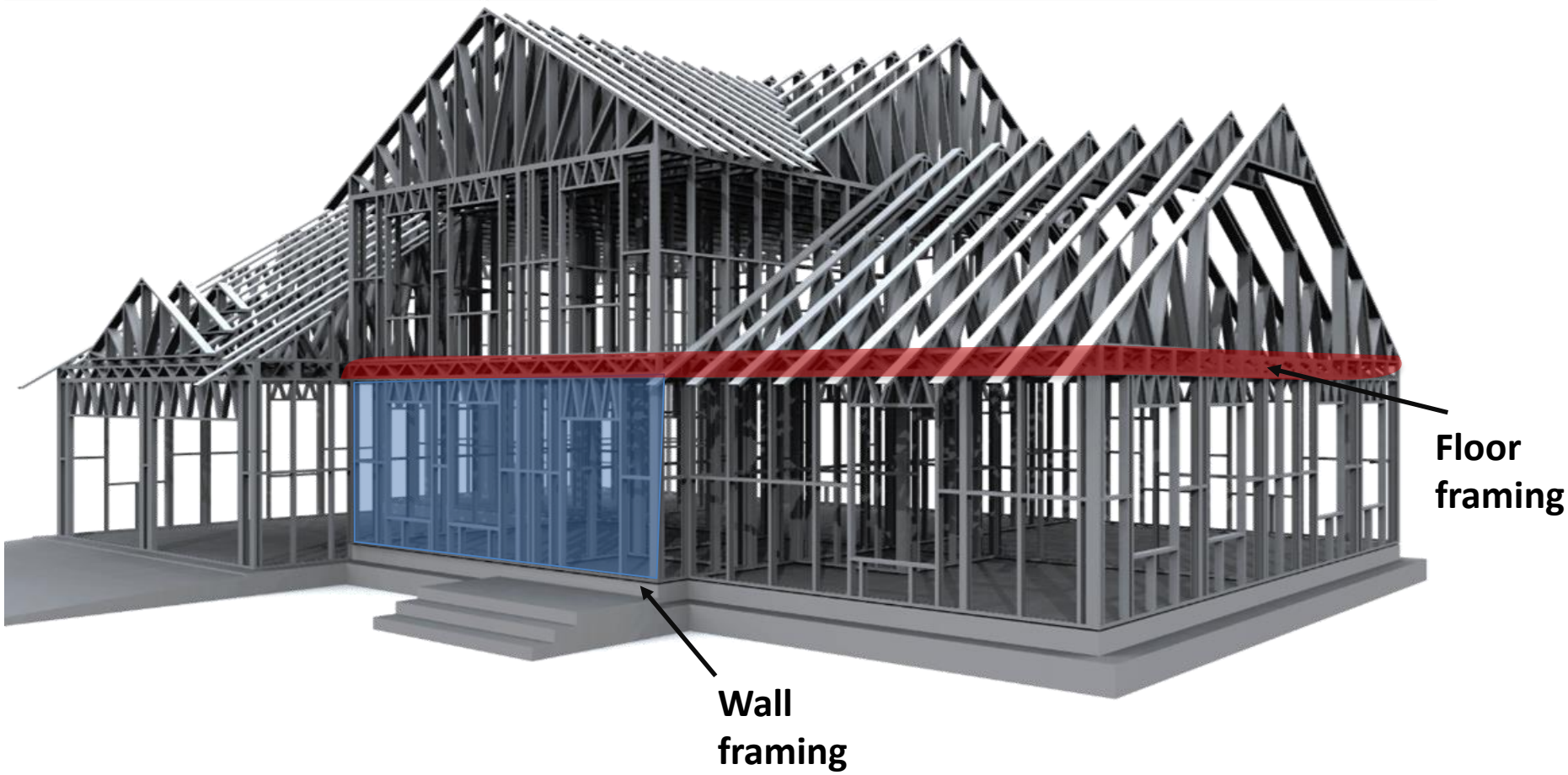
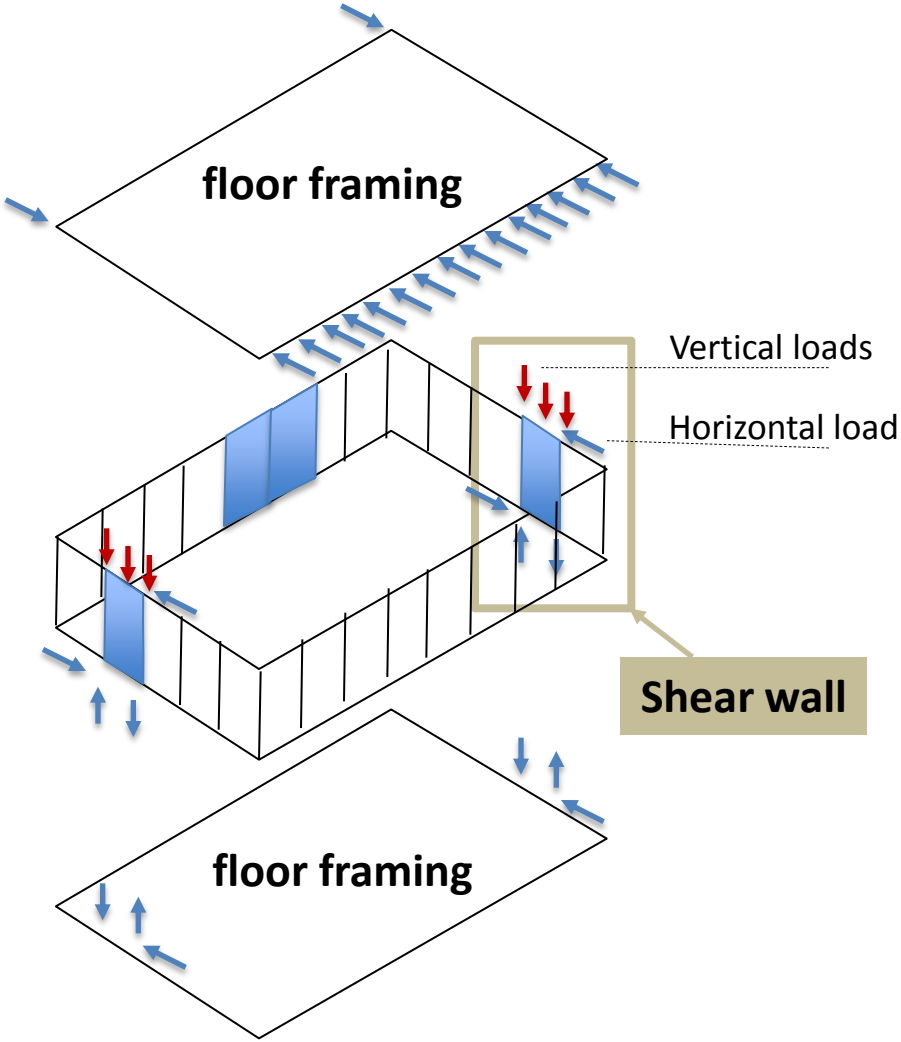
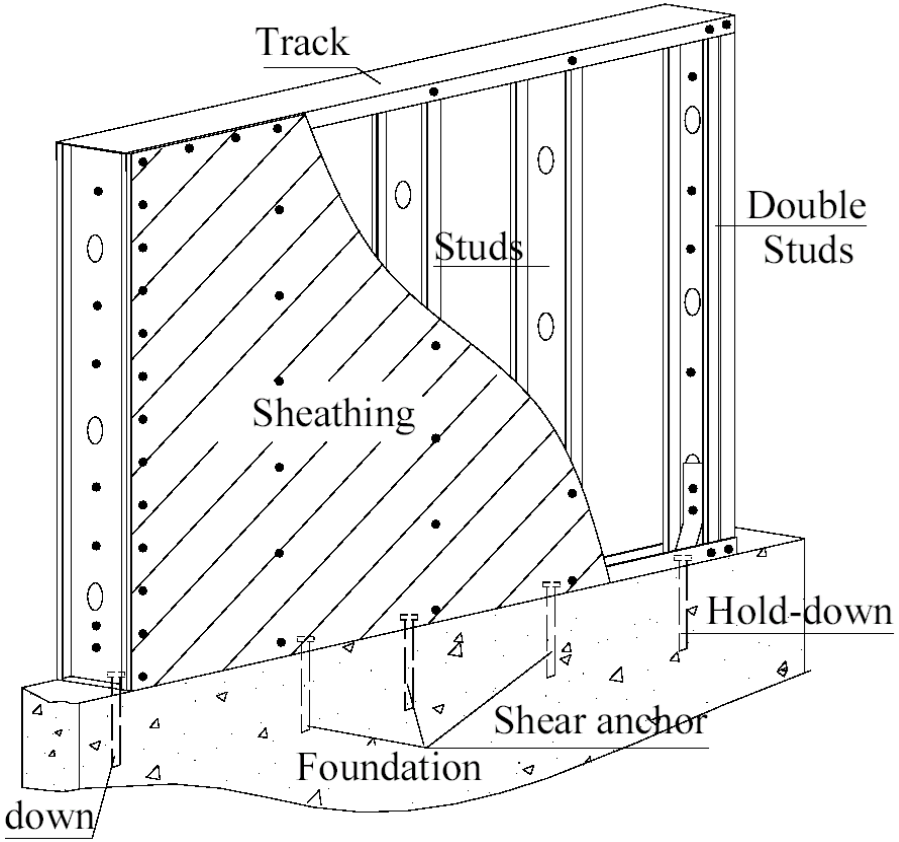
In the last years, the application of Lightweight Steel-Framed Constructions has spread especially in non-seismic areas, but how they should be designed **in seismic areas**?

The main structural subsystems of stick-built constructions can be identified in walls and floors



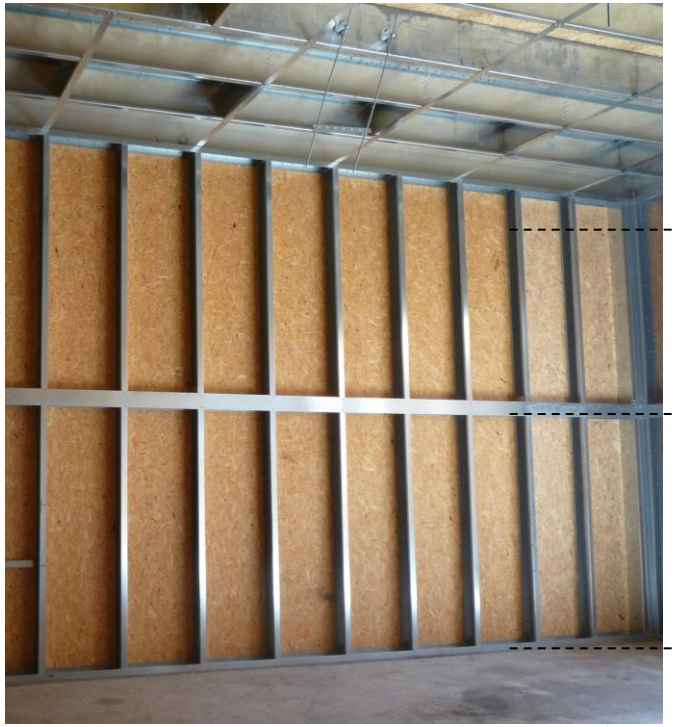
The load-bearing structural units under vertical and horizontal loads are the **Shear walls**

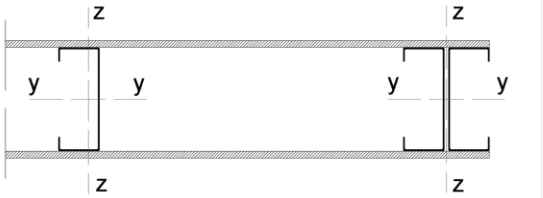


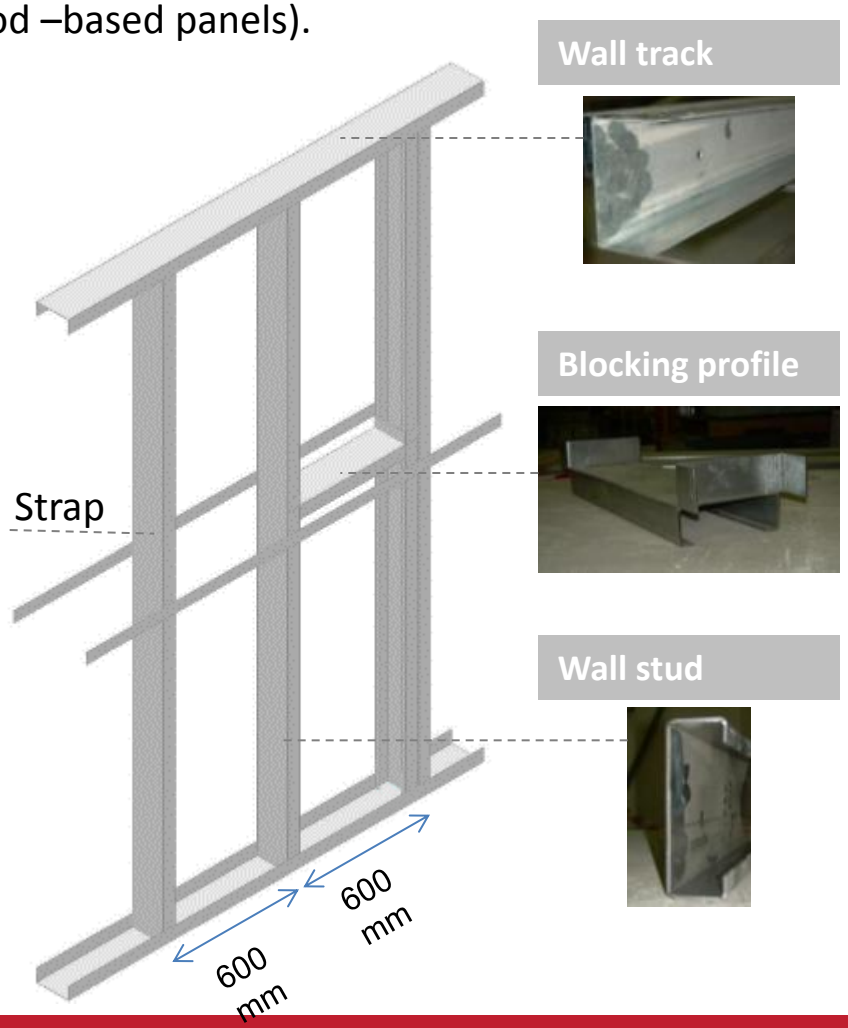


Main structural subsystems: wall framing

Load bearing walls are made of **studs**. The studs are fastened at each end to **wall tracks**. At mid wall height, **straps** can be connected to both flanges of the studs and **blocking profiles** can be introduced at wall ends. Walls are completed by **sheathing panels** (gypsum or wood –based panels).



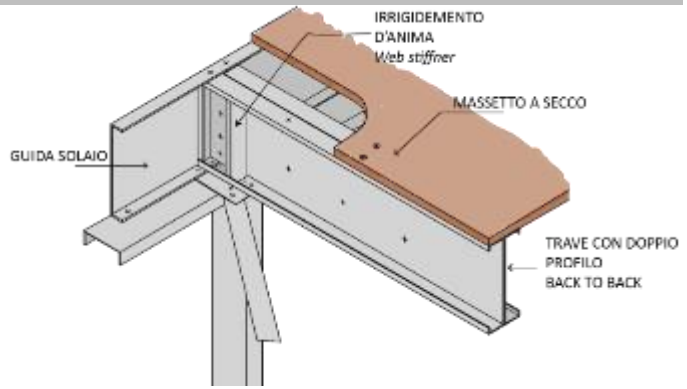




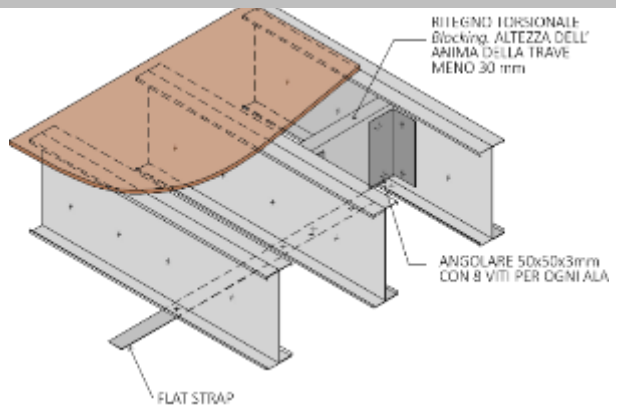
Main structural subsystems: floor framing

Floors are made of **joists**, located in line with the studs, and fastened at each end to **floor tracks**. At the joist ends, **bearing stiffeners** are used to strengthen the joists against web crippling. The top flange of joists is laterally braced by the **floor sheathing**, while the bottom flange can be braced by **straps** and **blocking.**

Web stiffner

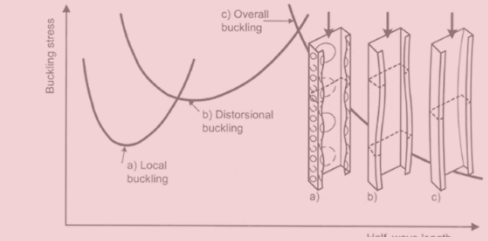


Blocking



The design of Lightweight Steel-Framed Constructions under vertical and horizontal loads can be carried out using two approaches:

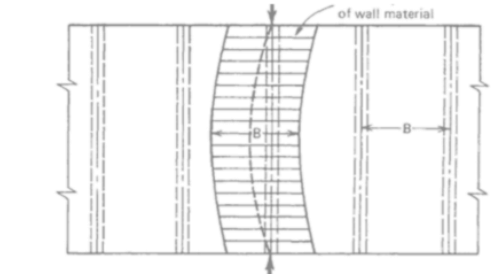
All-steel design



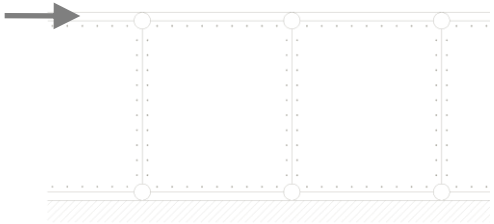
VERTICAL LOADS

HORIZONTAL LOADS

Sheathing-braced design



VERTICAL LOADS

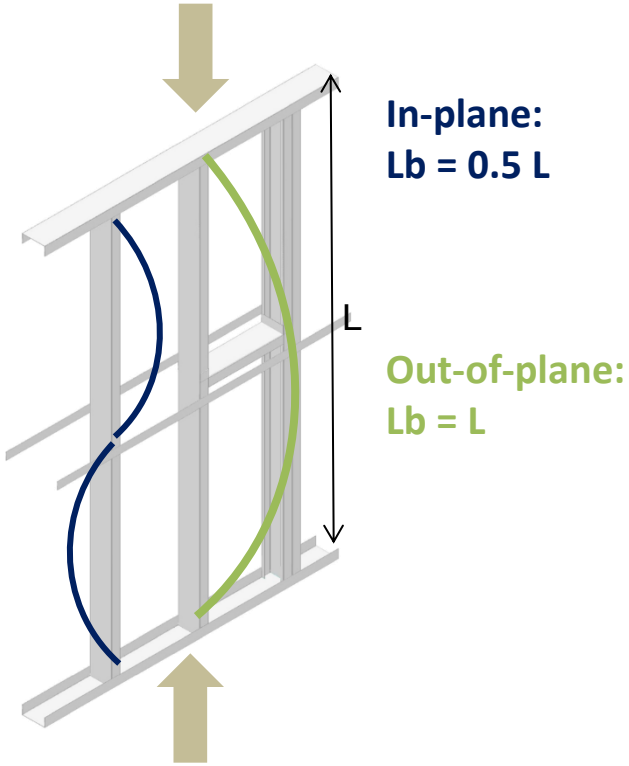


HORIZONTAL LOADS

All-steel systems: design under vertical loads

The all-steel approach does not consider the presence of sheathing panels and the generic profile is assumed as isolated (free-standing), by neglecting the interaction between the profile itself and the sheathing.

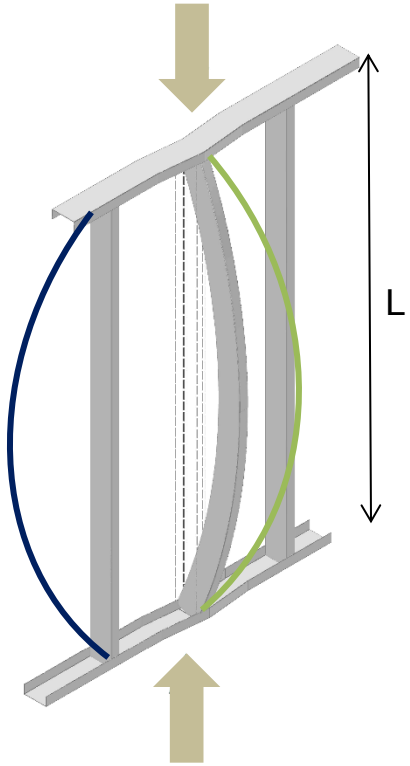
Case 1: wall with straps and blocking at mid wall height



In-plane:
Lb = 0.5 L

Out-of-plane:
Lb = L

Case 2: wall without straps and blocking at mid wall height



In-plane:
Lb = L

Out-of-plane:
Lb = L

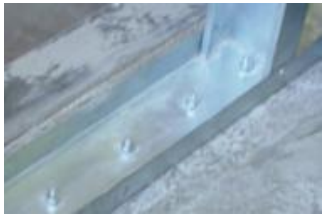
Global buckling of an "isolated" stud

Lb: buckling length, L: wall height

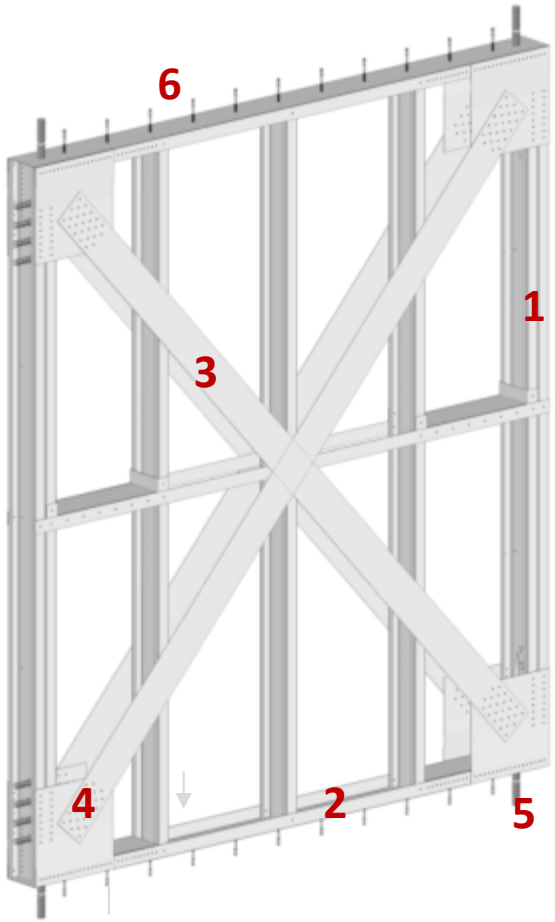
All-steel systems: design under horizontal loads

In the case of all-steel approach under horizontal actions, the in-plane resistance and stiffness are assured by **X-bracings** and steel straps are generally used to obtain the diagonal elements in walls, floors and roofs.

6 Shear anchorages



5 Tension anchorages



3 Diagonal straps

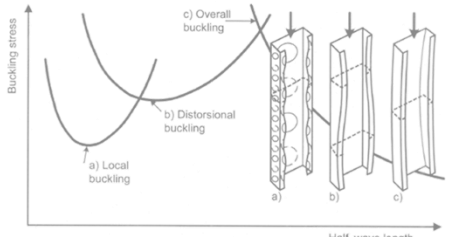
4 Diagonal joints

Main wall structural components:

1. Chord (end) studs
2. Wall tracks
3. **Diagonal straps**
4. Diagonal connections
5. Tension anchorages
6. Shear anchorages

The design of Lightweight Steel-Framed Constructions under vertical and horizontal loads can be carried out using two approaches:

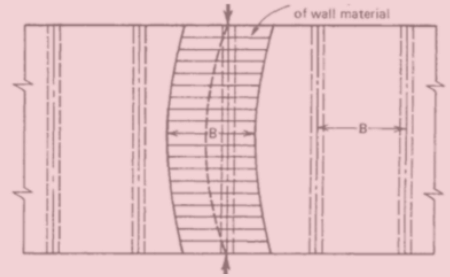
All-steel design



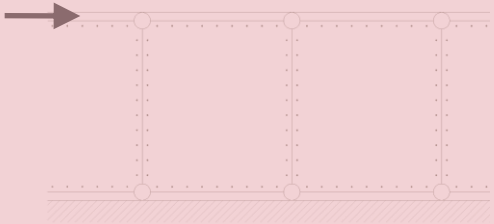
VERTICAL LOADS

HORIZONTAL LOADS

Sheathing-braced design



VERTICAL LOADS

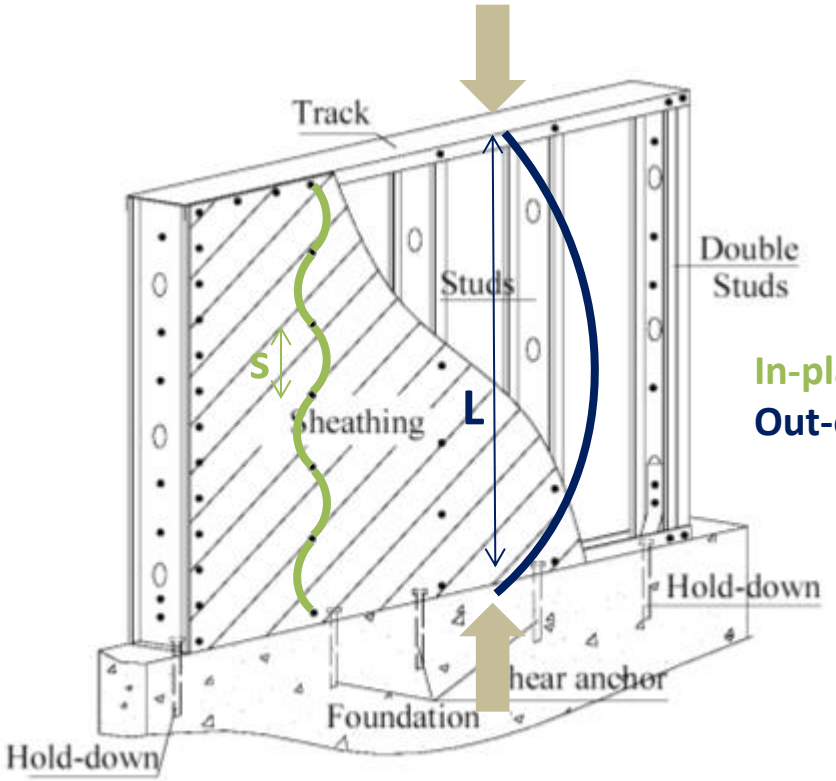


HORIZONTAL LOADS

Sheathing-braced systems: design under vertical loads

The sheathing-braced approach calculates the load bearing capacity of member taking into account the presence of sheathing panels. This is possible when the sheathing has adequate strength and stiffness and it is effectively connected to steel profiles.

Example: design of studs

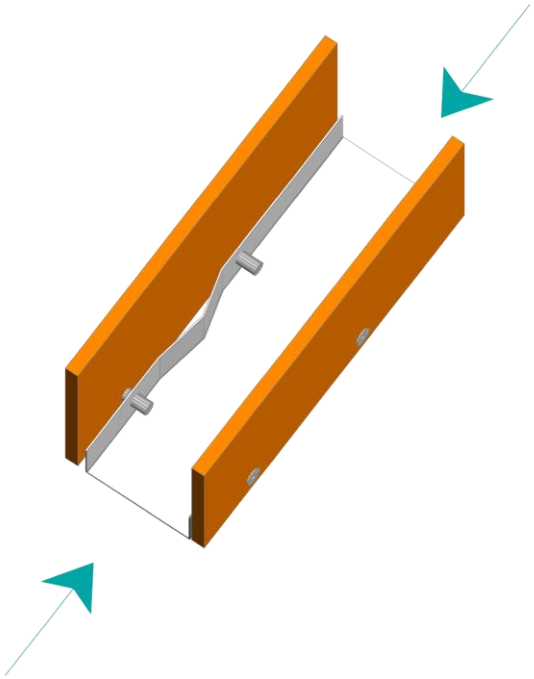


In-plane*: **Lb = 2 s**

Out-of-plane: Lb = L

Lb: buckling length, L: wall height, s: fasteners spacing

Local buckling of "sheathed" studs



*See: AISI S211 "North American Standard for Cold-Formed Steel Framing—Wall Stud Design

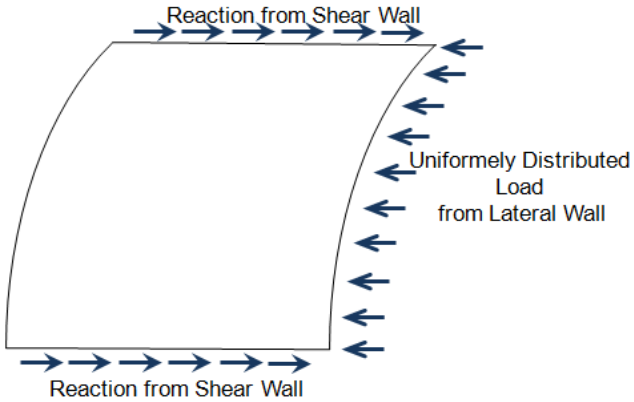
Sheathing-braced systems: design under horizontal loads

In the case of sheathing-braced approach under horizontal actions, the in-plane resistance and stiffness are assured by the interaction between sheathing panels and CFS frame.

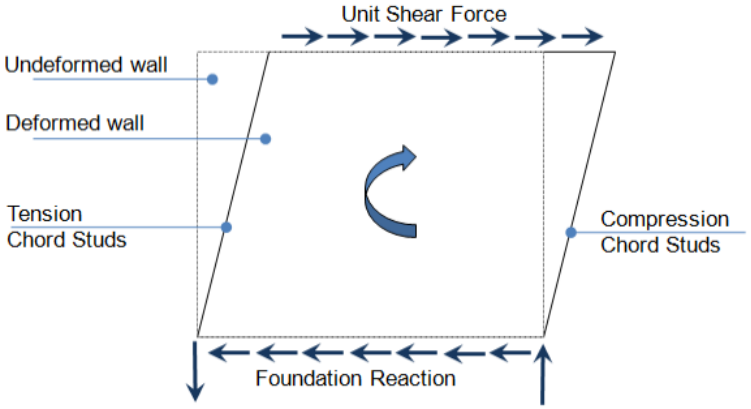
Main wall structural components:

1. Chord (end) studs
2. Wall tracks
3. Sheathing panels
4. **Sheathing fasteners**
5. Tension anchorages
6. Shear anchorages

Structural scheme of floor diaphragms



Structural scheme of walls diaphragms



Seismic design criteria according to Eurocode 8

Eurocode 8 does not provide any specific prescription for the design of lightweight steel constructions in seismic area.

All-steel structure

All-Steel Structures could be designed according a **DCL (low dissipative approach for low seismicity zones)** by assuming the behaviour factor equal to **1.5** without capacity design rules.

However, this approach may be restrictive, since the lightness of these systems makes them a good solution also for high seismicity zones

Sheathing- braced structure

Eurocode 8 **does not provide specifications** applicable to Sheathing-braced structures

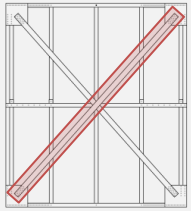
There is a gap between the European code specifications and the application of these systems in seismic areas

Seismic design criteria according to North American codes

North American Codes (**AISI S400** for USA, Mexico and Canada; **ASCE 7** for USA and Mexico; **NBCC** for Canada) allow the **dissipative design approaches** according to the Capacity design.

All-steel structure

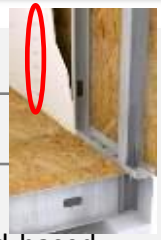
Strap-braces act as the energy-dissipating elements



	ASCE 7	NBCC
Behaviour factor	4.0 (bearing wall systems)	2.47
Overstrength factor	the non-dissipative elements designed by considering the forces corresponding to the expected yield strength of diagonal	

Sheathing- braced structure

Sheathing connections act as the energy-dissipating elements



	ASCE 7		NBCC	
Behaviour factor	6.5 (bearing wall systems)	7.0 (building frame systems)	4.25 (shear walls with wood-based structural panel sheathing	
Overstrength factor	2.5 (building frame systems)	3.0 (bearing wall systems)	1.33 (DFP and OSB panels)	1.45 (CSP wood panels)

CONTENTS

1. Introduction

2. Seismic design of CFS Constructions

3. Researches at the University of Naples Federico II

4. Case Study

5. Concluding Remarks

Motivations

1. The ongoing researches at the University of Naples "Federico II" have the main aim to bridge the gap between **the code specifications and the application** of Lightweight Steel-framed Constructions in seismic areas

2. The low-rise residential building sector **(housing)** recorded, in the last thirty years, an increment of Lightweight Steel-framed Constructions

3. The diffusion of these systems in the housing sector is due to the capability to satisfy the growing demand for **low-cost high performance houses.**

4. However, the use of Lightweight Steel-framed Constructions in Europe is still limited. This can be explained by the **reduced technical knowledge, especially in the case of seismic force resisting buildings.**

Structural all-steel systems

- Italian national research project
  ReLUIS-DPC, Line 1, years 2010-2013
- National research project
  Lamieredil-UNINA Project, years 2014-2017

Structural sheathing-braced systems

- National research project
  Prin, years 2001 - 2005
- European research project
  ELISSA Project, years 2013-2016

Structural all-steel systems

- Italian national research project
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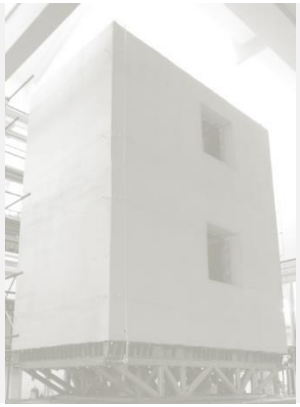
- National research project
  Lamieredil-UNINA Project, years 2014-2017



Structural sheathing-braced systems

- National research project
  Prin, years 2001 - 2005
- European research project
  ELISSA Project, years 2013-2016

Seismic response evaluation and optimization of structural all-steel systems

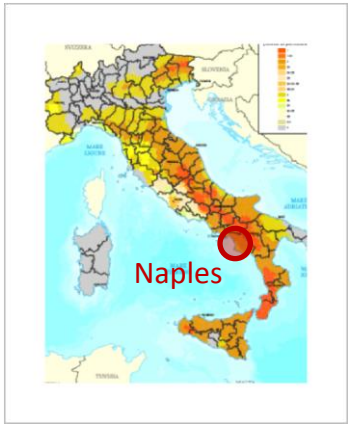
The Lamieredil project is a research funded by a manufacturer of cold-formed metal framing, the Lamieredil S.p.A. Company, Italy. The main goal of the study was the experimental characterization of the seismic response of low dissipative CFS all-steel strap-braced stud structures, obtained through an experimental activity on materials, products, components, single seismic resistant systems and whole structures.

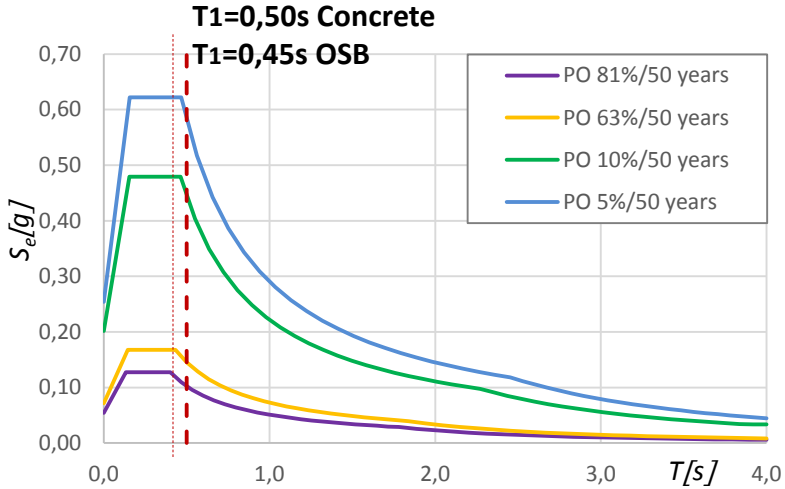
UNIVERSITY OF NAPLES FEDERICO II

Department of Structures for Engineering and Architecture

Lamieredil SpA
il metallo prende forma

Case study and design assumptions

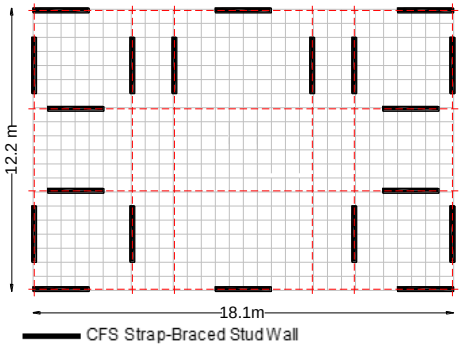




PO: Probability of occurrence

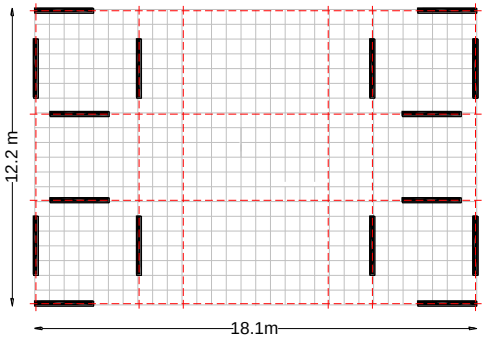
PO	a_g [g]	PGA [g]	Sa (0.50s) [g] CONCRETE	Sa (0.45s) [g] OSB
81%/50	0.05	0.05	0.10	0.11
63%/50	0.06	0.07	0.15	0.16
10%/50	0.17	0.20	0.55	0.49
5%/50	0.21	0.25	0.58	0.65

Type 1 building (Concrete solution)



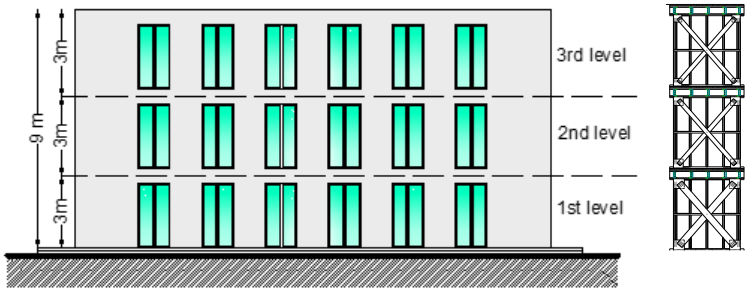
10 CFS strap-braced stud walls

Type 2 building (OSB solution)



8 CFS strap-braced stud walls

ELASTIC DESIGN APPROACH
(q=1)



The studied building, with rectangular plan, covered an area of 220 m^2 and three storeys with a storey height of 3.00 m.

General experimental program

Test type		no. tests
Material, component and connections tests	Steel material	12
	Self-drilling screws	3
	Joints between gussets plate and strap-brace	6
	Hold-down device	4
Wall tests	In-plane monotonic tests	2
	In-plane quasi-static reversed cyclic tests	4
Shake table of 3D prototypes	Dynamic identification and earthquake tests	16 + 14 on 2 prototypes
	Total no. of tests	***61***

1:3 Reduced scale specimens

Tests on materials, components and connections

Tests on steel materials

Total tests: 12

Tests on Self-drilling screws

Total tests: 3

Tests on joints between gussets plate and strap-brace

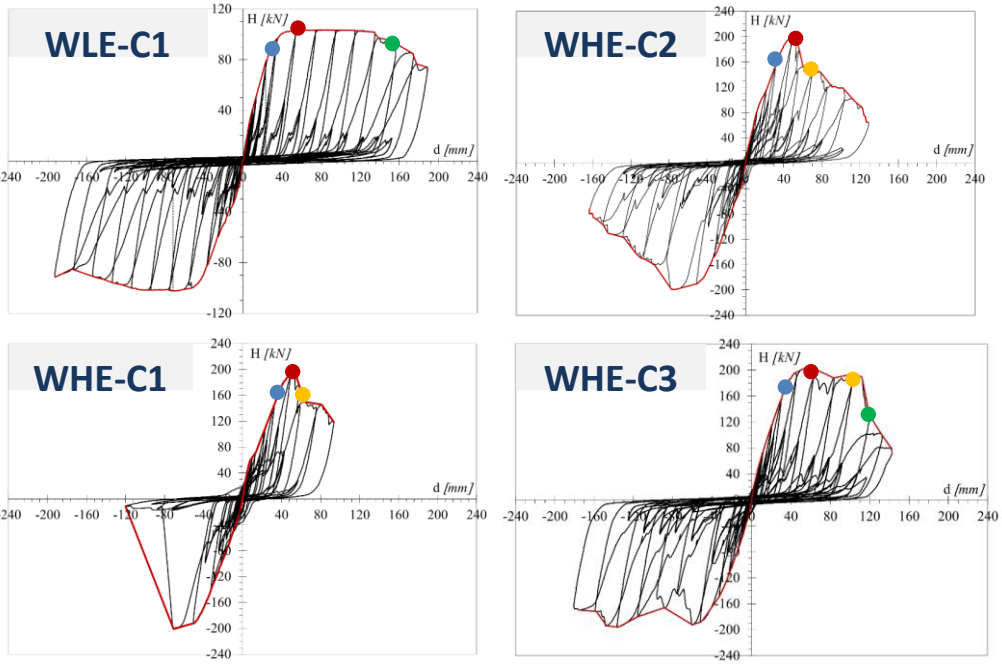
Total tests: 6

Tests on hold-down devices

Total tests: 4

In-plane quasi-static reversed cyclic tests on wall specimens

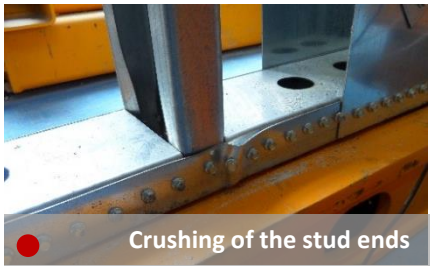
Test results



4 cyclic tests

Failure modes

Local buckling of the tracks


Crushing of the stud ends

Gusset-to-track connection failure

Plastic hinges in chord studs

From the case study to the 1:3 reduced scale specimens for shake table tests

The reduced-scale specimens were defined starting from a part of the full-scale case study (i.e. A_1=12.8 m^2 and A_2=6.10 m^2)

Two different specimens:

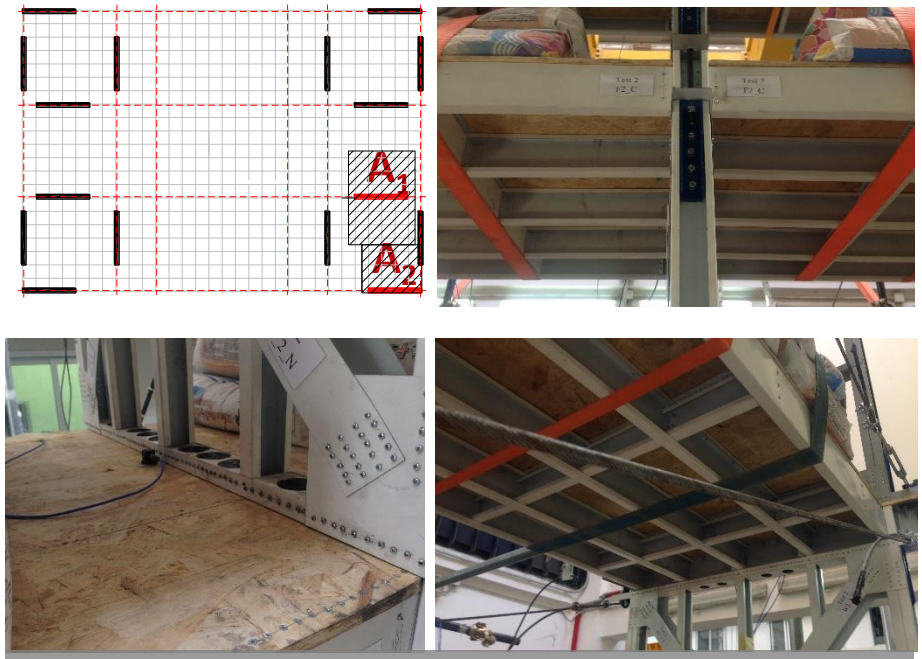
- **prototype with composite steel-concrete floors;**
- **prototype with wood-based (OSB panels) sheathing-braced floors.**

Both specimens have nominally identical CFS strap-braced stud walls.

Type 1 building (concrete solution)

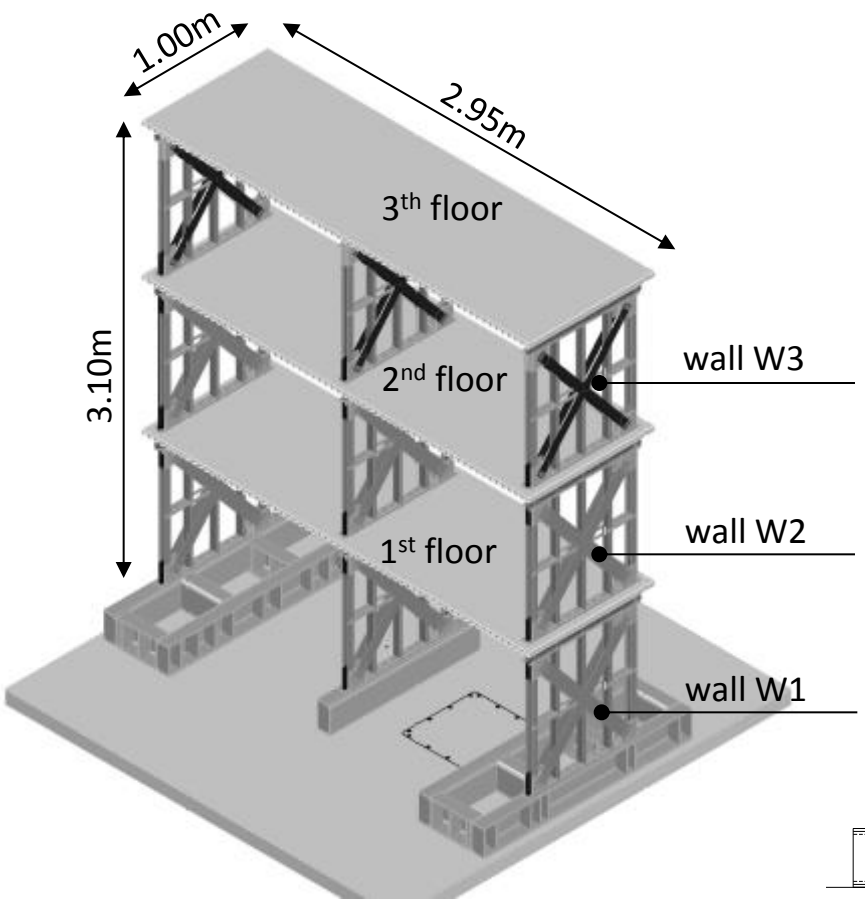
Prototype with composite steel-concrete floors

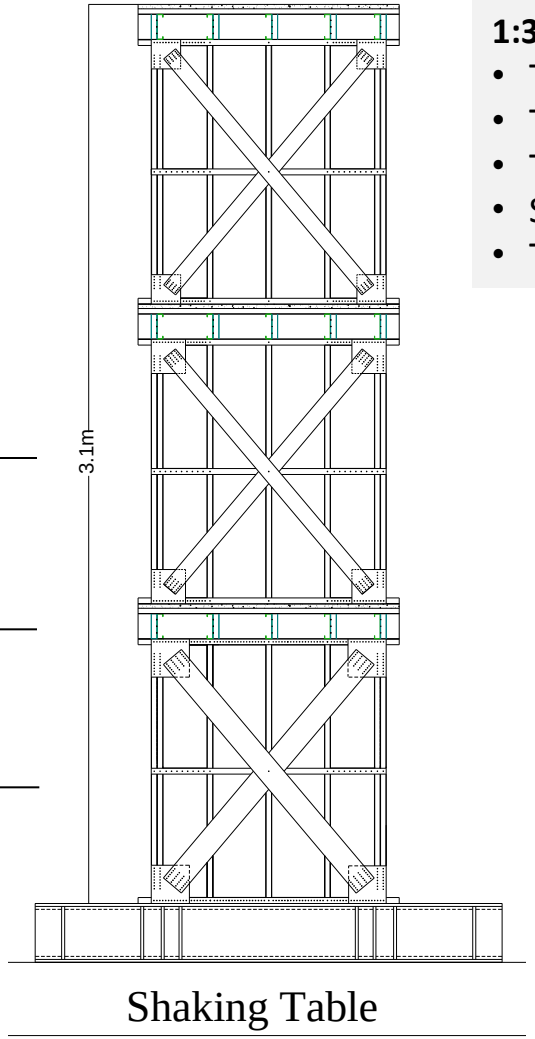
Type 2 building (OSB solution)



Prototype with wood-based (OSB panels) sheathing braced floors

1:3 reduced scale CFS three-storeys strap-braced stud structures

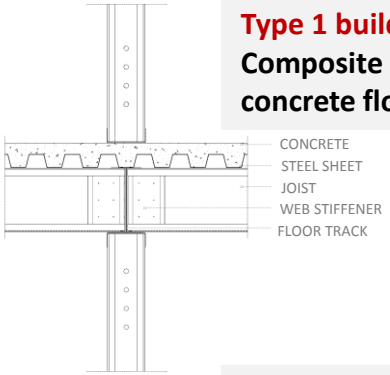




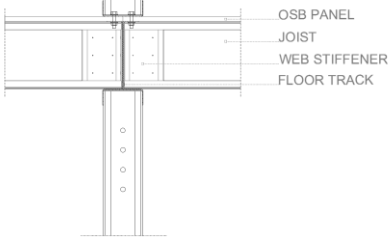
1:3 REDUCED SCALE SPECIMEN:

- Three storeys building
- Two bays
- Total area: 3 x 2.8 m^2= 8.4 m^2
- Storey height: 1.03 m
- Total height: 3.10 m

Type 1 building: Composite steel-concrete floor



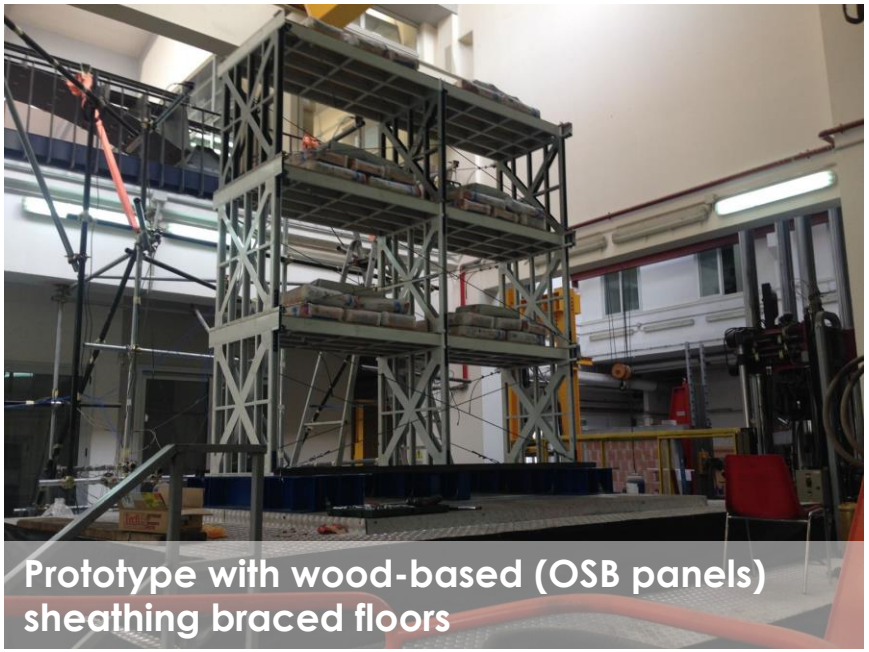
Type 2 building: Wood-based (OSB panels) sheathing-braced floors



Experimental program for shake table tests

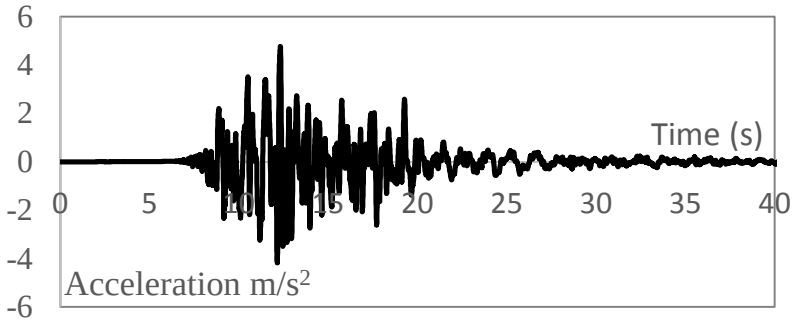
1:3 reduced scale CFS three-storeys strap-braced stud structures	Dynamic identification tests	Dynamic earthquake tests
Prototype with composite steel-concrete floors	8 tests (0,036g)	7 tests (9 – 150 % Scaling Factor)
Prototype with wood-based (OSB panels) sheathing-braced floors	8 tests (0,028 g)	7 tests (9 – 150 % Scaling Factor)

Prototype with composite steel-concrete floors


Prototype with wood-based (OSB panels) sheathing braced floors

Dynamic earthquake tests - Input: 2016 Norcia Earthquake

Input time history NRC-EW

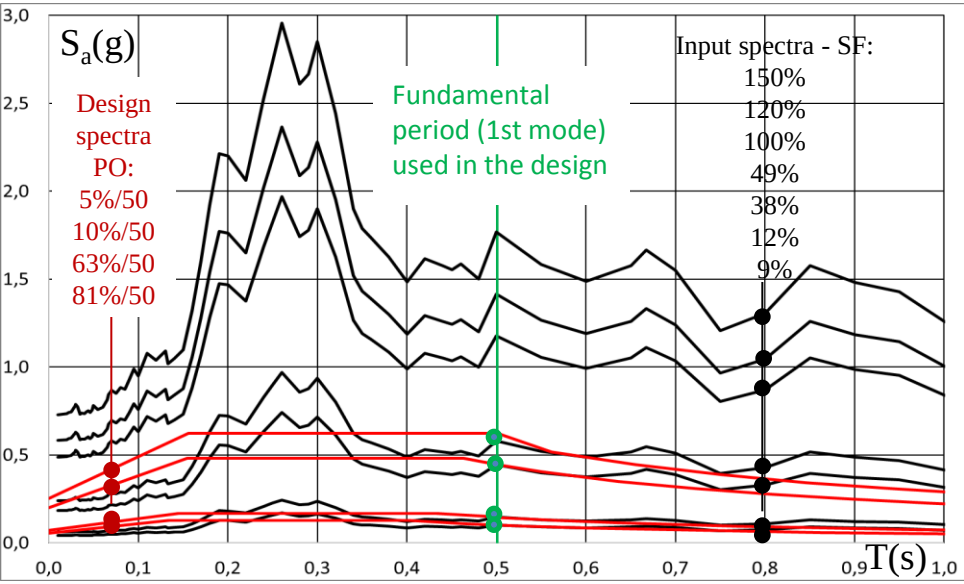


SELECTED GROUND MOTION

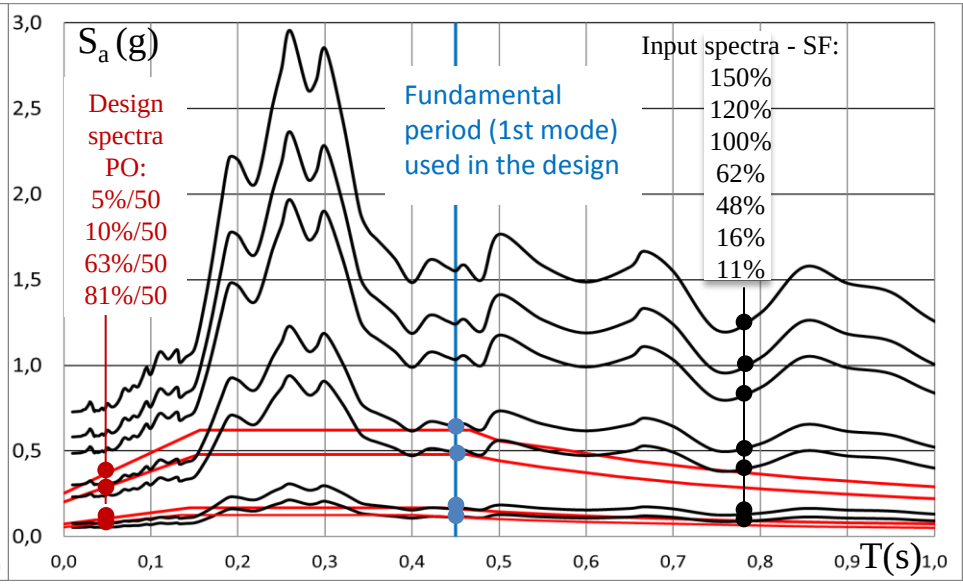
Event:	*Norcia – October 30th, 2016 6:40 a.m.*
Magnitude:	Mw= 6.5
Station:	*Norcia*
Station code:	*NRC*
PGA:	*4.76 m/s²* (0,49 g)

Input spectrum vs. design spectrum (S_a-T format)

Concrete solution



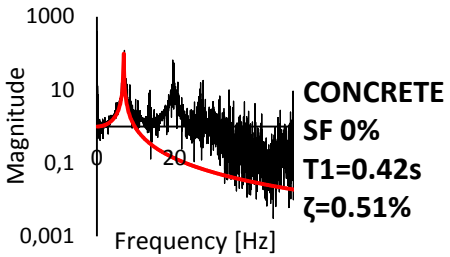
OSB solution

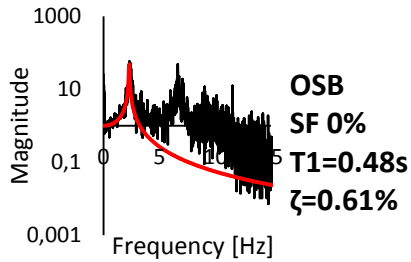


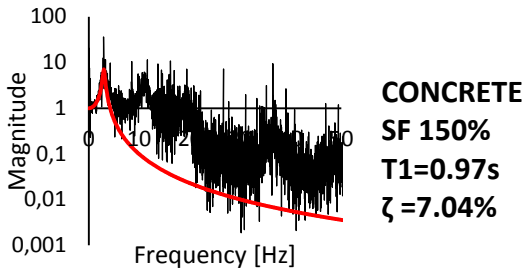
SF: Scaling Factor; PO: Probability of occurrence

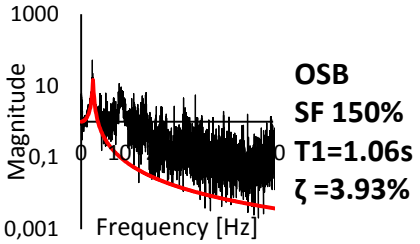
Dynamic identification tests

Dynamic identification were carried out with the transfer curve method in the frequency domain.









Fundamental vibration period

Concrete structure

Before EA tests
- T=0.43s

After EA tests
- T=0.98s

(EA produced an increasing of 2.3 times)

OSB structure

Before EA tests
- T=0.48s

After EA tests
- T=1.06s

(EA produced an increasing of 2.2 times)

Damping ratio

Concrete structure

Before EA tests
- ζ =0.5%

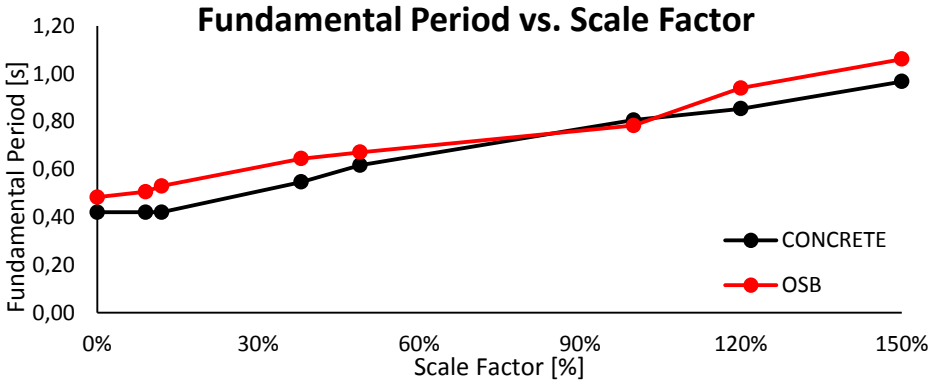
After EA tests
- ζ =7%

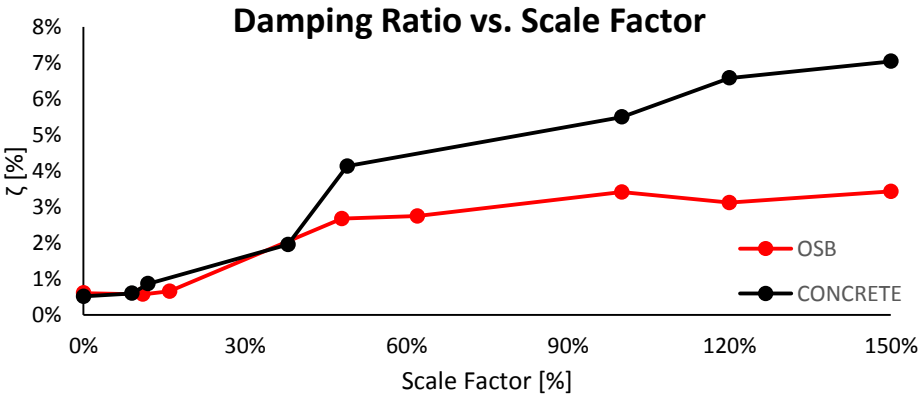
(EA produced an increasing of 14 times)

OSB structure

Before EA tests
- ζ =0.6%
- After EA tests
- ζ =3%

(EA produced an increasing of 5 times)





Dynamic earthquake tests

Maximum top displacement

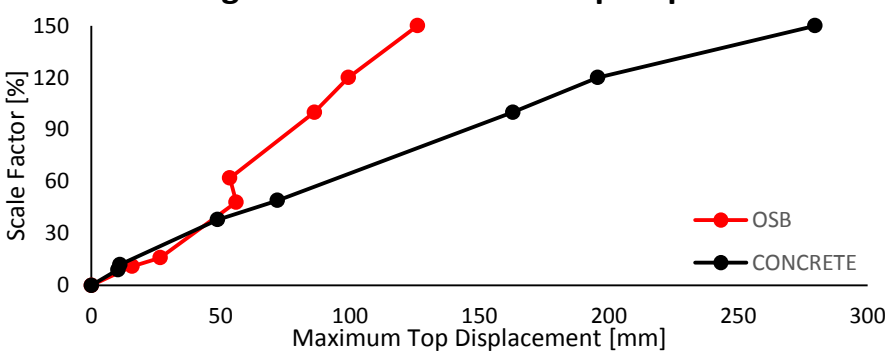
Concrete structure

For all SF, the global response was almost **linear** for CONCRETE solution.
Maximum top displacement obtained for CONCRETE solution (**280 mm**).

OSB structure

For all SF, the global response was almost **linear** for OSB solution.
Maximum top displacement obtained for OSB solution (**128 mm**).

Scaling factor vs. maximum top displacement



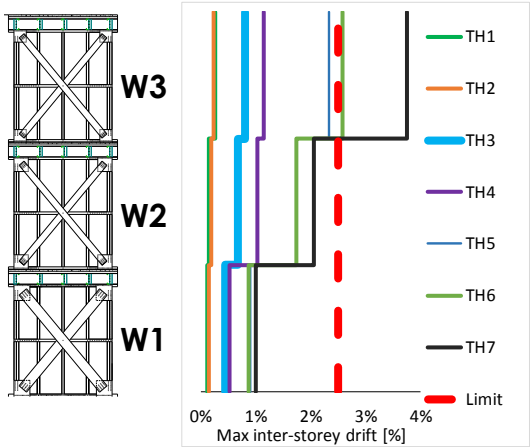
Building inter-storey drift

The maximum values were recorded for the input with maximum intensity (scaling factor of 150%) at the 3rd level: **3,75% for CONCRETE solution** and **2,40% for OSB solution**

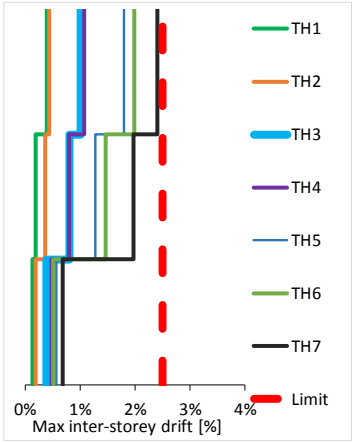
Recorded maximum inter-storey drift

Test label	Max inter-storey drift [%]					
	1st Level		2nd Level		3rd Level	
	CONC.	OSB	CONC.	OSB	CONC.	OSB
TH1	0.11	0.13	0.14	0.19	0.26	0.39
TH2	0.14	0.19	0.18	0.36	0.23	0.43
TH3	0.43	0.38	0.66	0.80	0.80	1.00
TH4	0.51	0.48	1.03	0.80	1.14	1.08
TH5	0.90	0.57	1.73	1.27	2.33	1.79
TH6	0.86	0.51	1.73	1.46	2.58	1.99
TH7	1.00	0.68	2.05	1.97	**3.75**	**2.40**

Concrete structure



OSB structure



Dynamic earthquake tests

Damage phenomena

Concrete structure

Observed phenome:

- Strap yielding
- Bolt loosening
- Shear failure of screws

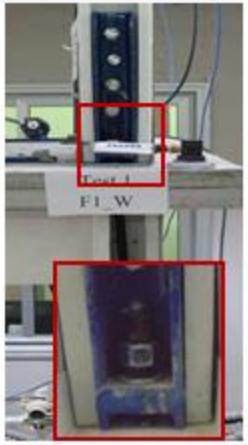
OSB structure

Observed phenome:

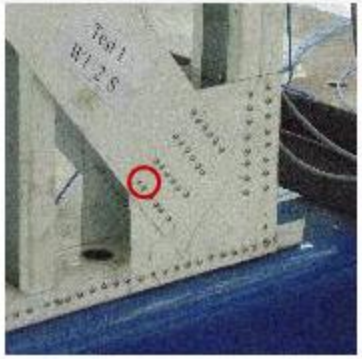
- Strap yielding
- Bolt loosening
- Local buckling of chord stud

Straps yielding

Bolt loosening



Shear failure of screws



Stud local buckling

Diaphragms response

Diaphragm response was evaluated according to ASCE 7.

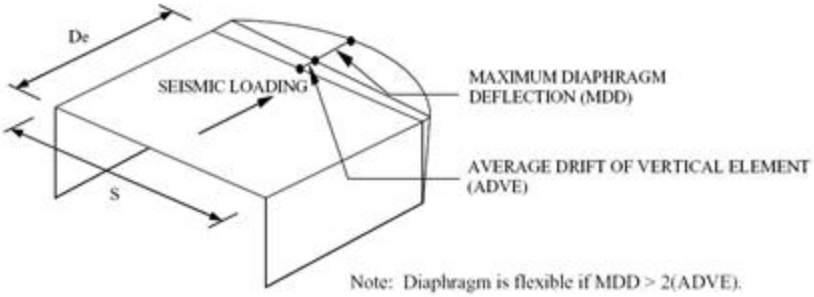


FIGURE 12.3-1 FLEXIBLE DIAPHRAGM

Recorded MDD and ADVE values

Test label	MDD [mm]		AVDE [mm]		MDD/AVDE*	
	CONC.	OSB	CONC.	OSB	CONC.	OSB
TH1	0.71	1.96	1.89	0.70	0.38	2.78
TH2	0.62	1.70	2.04	2.46	0.31	**0.69**
TH3	0.83	0.26	7.28	8.38	0.11	0.03
TH4	0.45	0.18	10.17	7.63	0.04	0.02
TH5	0.22	0.51	18.96	16.06	0.01	0.03
TH6	1.05	0.052	19.98	18.08	0.05	0.00
TH7	1.06	0.912	19.67	22.48	0.05	0.041

Max **MDD/ADVE=0,69** for OSB solution: according to the ASCE 7 definition, **diaphragms can be assumed as rigid** in their plane (neglecting TH1 for OSB solution).

** Limit value (ASCE 7) for rigid diaphragms= 2,00*

Structural all-steel systems

- Italian national research project
  ReLUIS-DPC, Line 1, years 2010-2013
- National research project
  Lamieredil-UNINA Project, years 2014-2017

Structural sheathing-braced systems

- National research project
  Prin, years 2001 - 2005
- 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**).

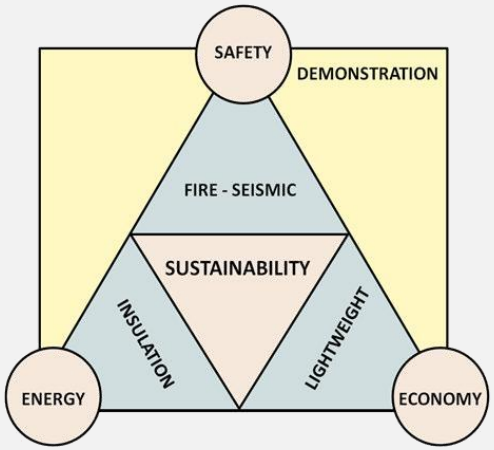
ELISSA Research Project

Energy Efficient LIghtweight – Sustainable – SAfe – Steel Construction

PARTNERS

Project objective

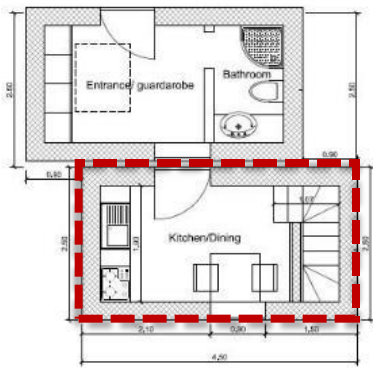
The ELISSA project was devoted to the development and demonstration of **nano-enhanced prefabricated lightweight Cold-Formed Steel (CFS) skeleton/dry wall constructions** with improved of energy efficiency, fire and seismic safety and sustainability.



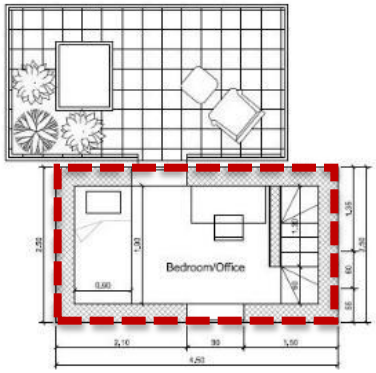
The case study: The "ELISSA house"

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**)

Design assumptions and structural design

Loads [EN 1991]

Roof: 2.00 kN/m² (snow); Floors: 2.00 kN/m² (live); Wind: 0.85 kN/m²

Seismic action [EN 1998]

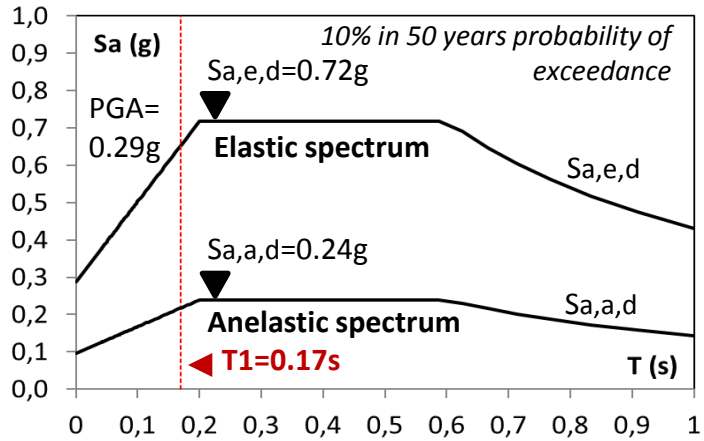
Medium to high intensity seismic area:

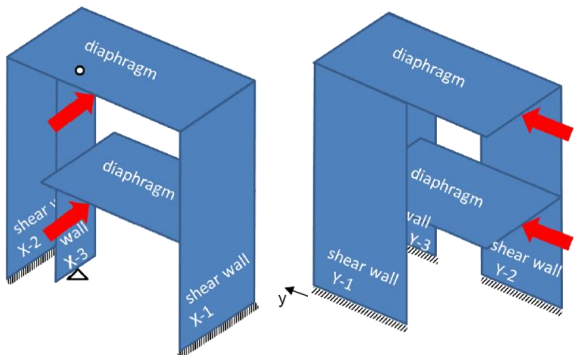
- Hazard level: 10% in 50 years probability of exceedance
  - reference PGA of 0.29g
  - design elastic spectral acceleration (Sa,e,d) equal to **0.72g**
- Hazard level: 2% in 50 years probability of exceedance
  - reference PGA of 0.44g
  - design elastic spectral acceleration (Sa,e,d) equal to 1.08g

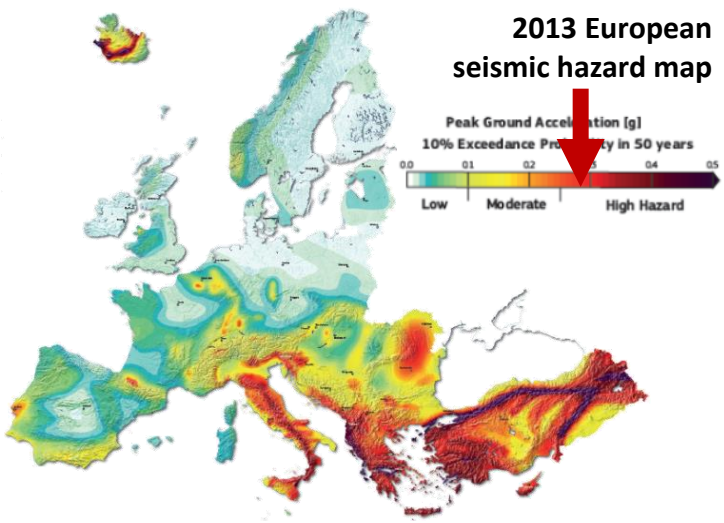
Behaviour factor q: 3.0

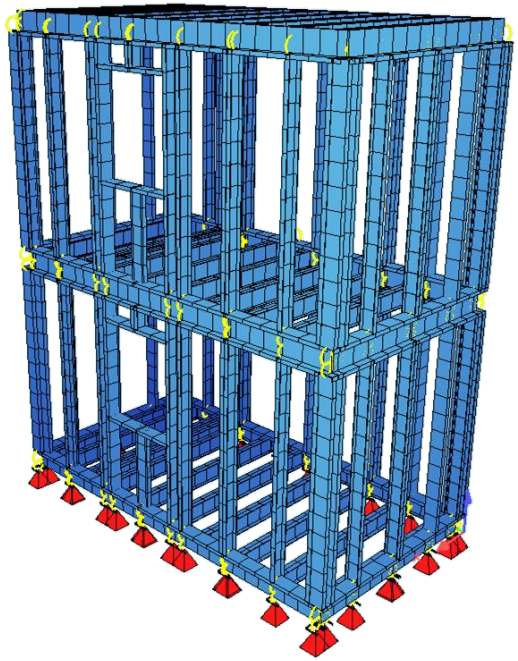
Overstrength factor Ω: 1.8

Elastic (Sa,e,d) and anelastic (Sa,a,d) design response spectra









3. Researches at the University of Naples "Federico II"

General experimental program

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

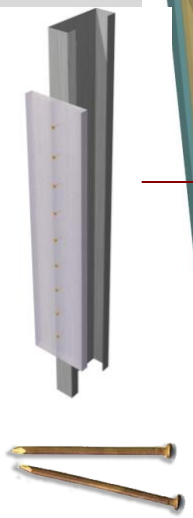
Panel-to-steel connections for floors

Balistic nails 3,4mm

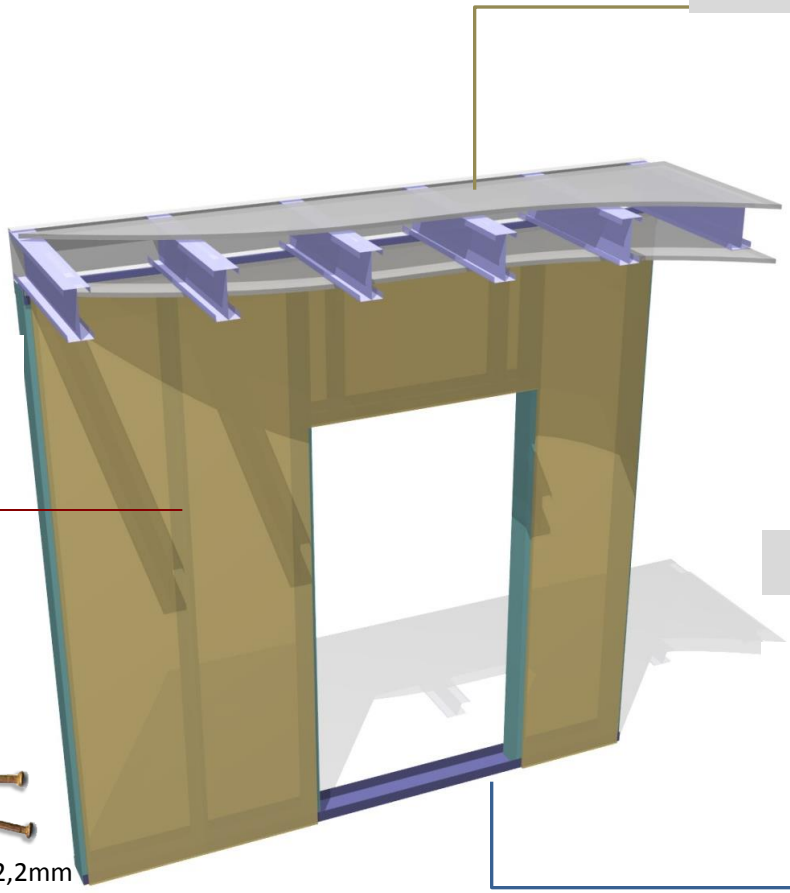
Total tests: 7

Panel-to-steel connections for walls

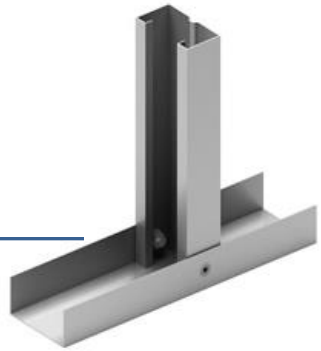
Total tests: 11



Balistic nails 2,2mm



Steel-to-steel connections

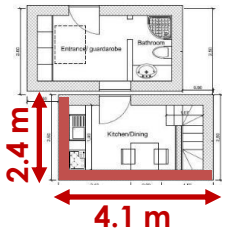


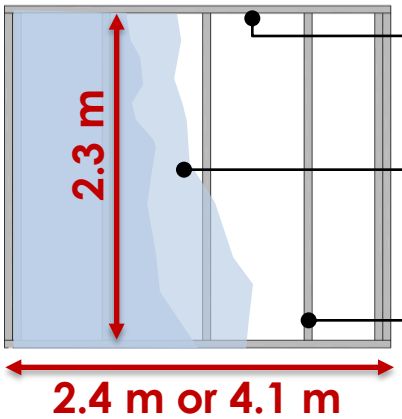
Clinching 8mm

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

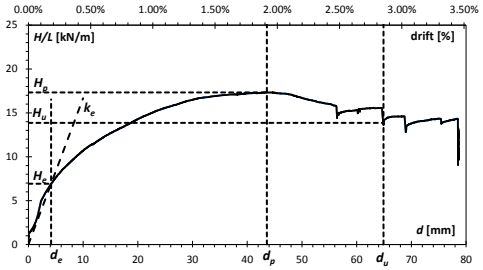
Studs: C147/50/1.5 mm

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

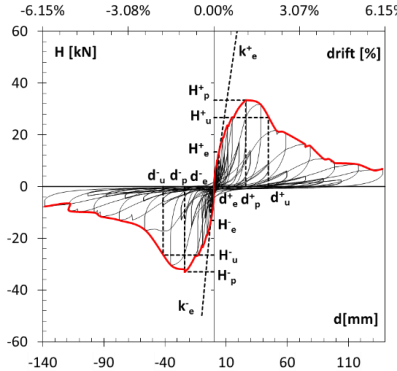
1 monotonic test and 3 cyclic tests

Experimental results

Short walls (2.4x2.3 m)



Long walls (4.1x2.3 m)



Failure mode: panel-to-frame connection failure

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

Dynamic earthquake tests - Input: 2009 L'Aquila Earthquake

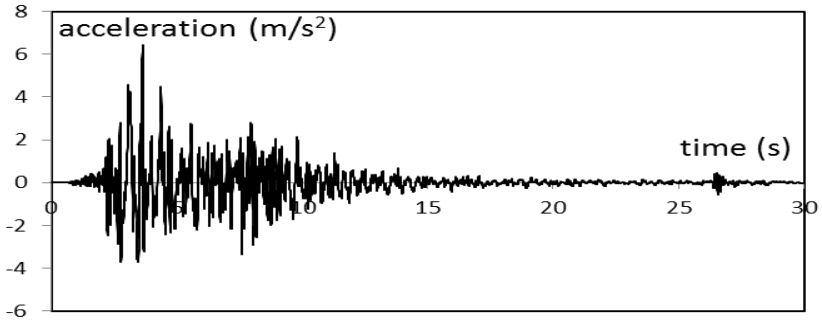
Mercalli Intensity (effects): 8-9
Richter magnitude (energy): 5.8

Damage caused by Aquila earthquake on traditional buildings

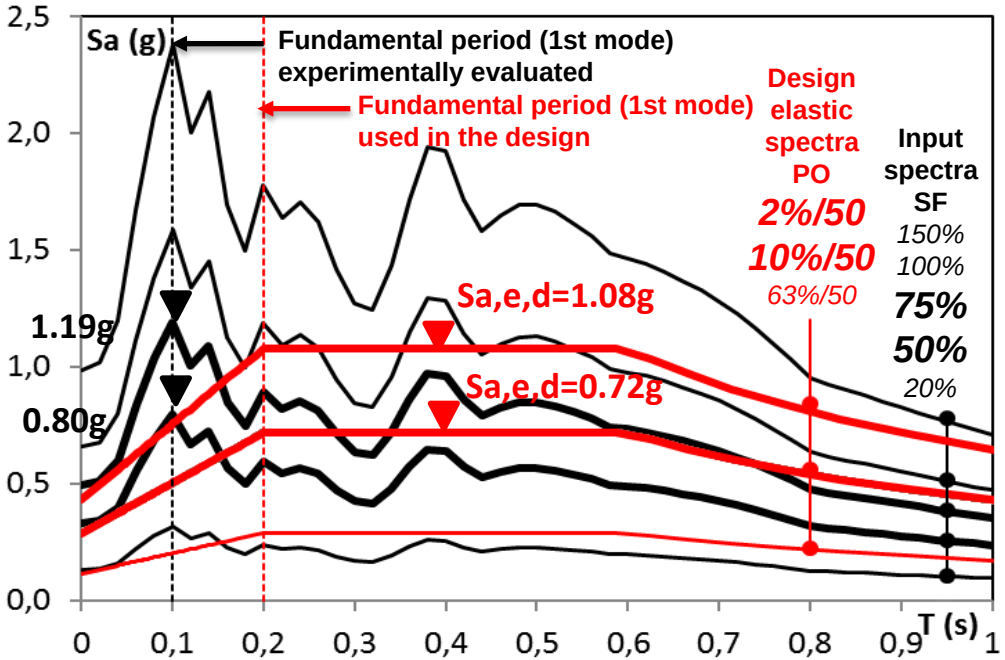
SELECTED GROUND MOTION

Event: *L'Aquila - April 6th, 2009 3:33 a.m.*
Magnitude: Mw= 6.2
Station: *L'Aquila - Valle Aterno - Centro Valle*
Station code: *AQV*
PGA: *6.44 m/s²* (0,66 g)

Input time history AQV-EW



Input spectrum vs. design spectrum (S_a-T format)



SF: Scaling Factor; PO: Probability of occurrence

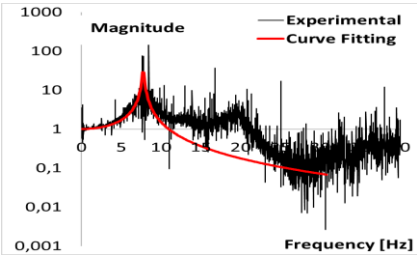
Earthquake test on shake table of the ELISSA mock-up

External view	Internal view (2nd floor)

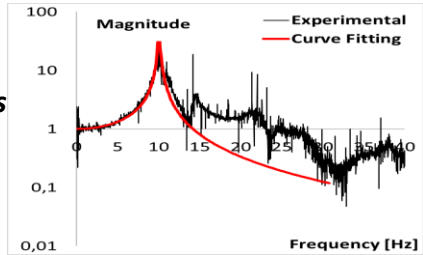
*Videos recorded during the Earthquake test with scaling factor of **150%***

Dynamic identification tests

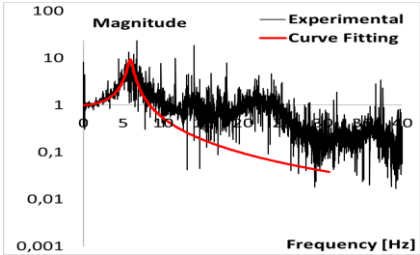
Dynamic identification were carried out with the transfer curve method in the frequency domain.



Bare structure
Before EA tests
SF 0%
T1=0.13s



Complete structure
Before EA tests
SF 0%
T1=0.10s
ζ =7.04%



Complete structure
After EA tests
SF 150%
T1=0.15s

Fundamental vibration period

Bare structure

Before EA tests

- T=0.13s

Complete structure

Before EA tests

- T=0.10s

After EA tests

- T=0.15s

*The **influence of finishing material** resulted in a decreasing of the fundamental period of about 20%.*

Damping ratio

Bare structure

Before EA tests

- ζ =1%÷3% (average value 2%)

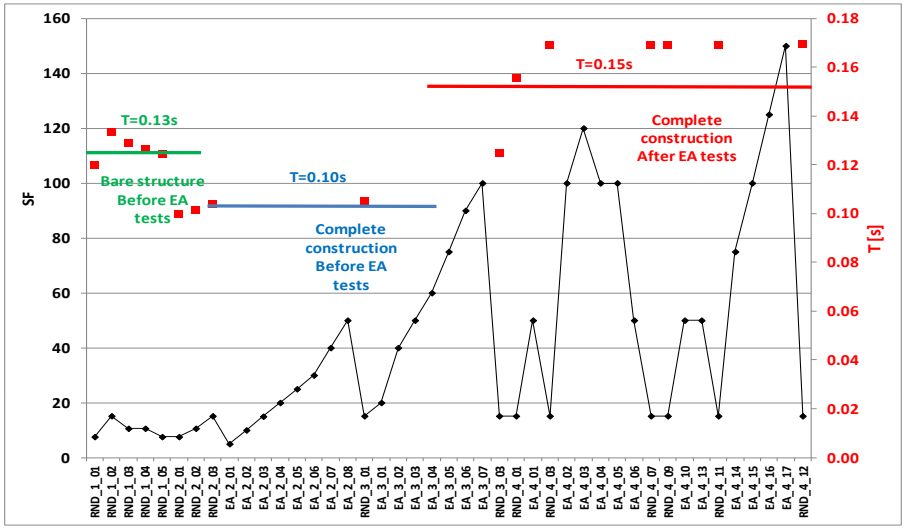
Complete structure

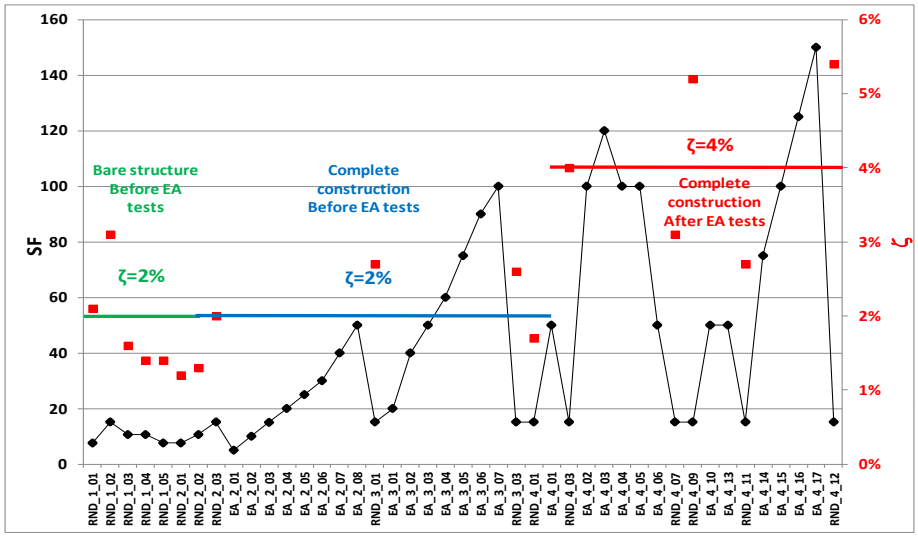
Before EA tests

- ζ =1%÷2% (average value 2%)

After EA tests

- ζ =2%÷5% (average value 4%)



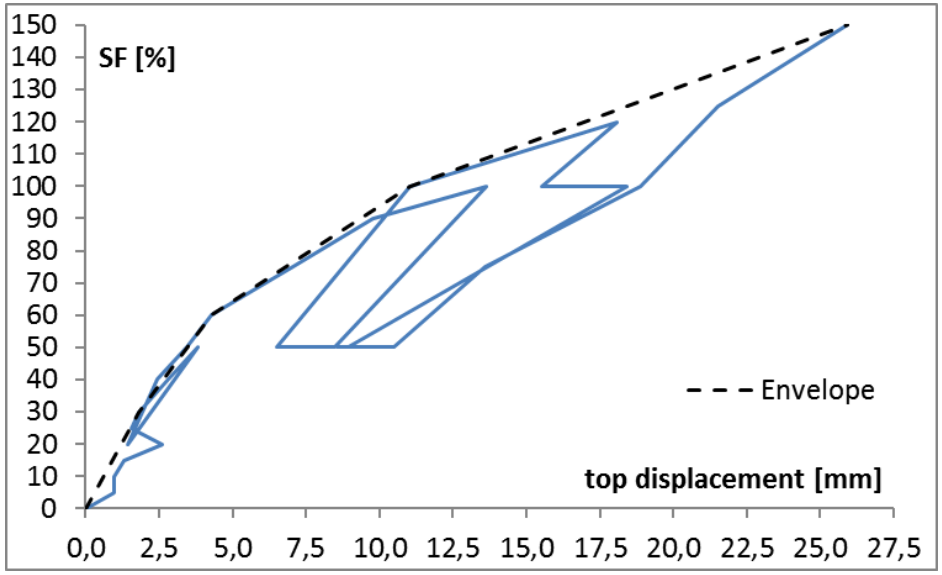


Dynamic earthquake tests

Maximum top displacement

For maximum top displacement less than about 4 mm, which corresponds to a scale factor of about 6**0%, the behaviour was linear,** whereas for higher maximum top displacements the **nonlinear response** became evident.
Maximum top displacement was recorded equal to **25.9 mm**).

Scaling factor vs. maximum top displacement



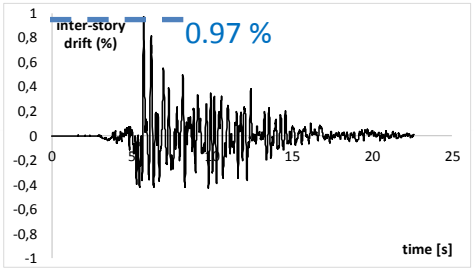
Building inter-storey drift

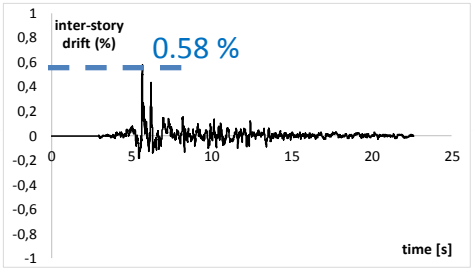
The values of inter-storey drift ratios were very small. The maximum values were recorded for the input with maximum intensity (scaling factor of 150%): **0.97% at the 1st level** and **0.58% at the 2nd level.**
The residual inter-storey drifts were negligible (under 0.06%), evidencing **a very modest anelastic behaviour.**

Recorded maximum inter-storey drift

Test label	Max inter-story drift (%)	
	1st level	2nd level
EA_2_01, 2_02, 2_03, 2_04, 2_05, 2_06, 2_07, 2_08	0.04, 0.05, 0.06, 0.07, 0.06, 0.07, 0.15, 0.18	0.03, 0.03, 0.04, 0.14, 0.05, 0.07, 0.09, 0.09
EA_3_01, 3_02, 3_03, 3_04, 3_05, 3_06, 3_07	0.06, 0.09, 0.12, 0.14, 0.17, 0.32, 0.42	0.06, 0.07, 0.12, 0.14, 0.24, 0.14, 0.19
EA_3_08	0.28	0.13
EA_4_01, 4_02, 4_03, 4_04	0.11, 0.20, 0.30, 0.27	0.14, 0.16, 0.17, 0.14
EA_4_05	0.26	0.12
EA_4_06	0.19	0.09
EA_4_10	0.18	0.09
EA_4_13, 4_14, 4_15, 4_16, 4_17	0.31, 0.42, 0.62, 0.65, **0.97**	0.16, 0.19, 0.28, 0.38, **0.58**

Story drifts time history under EA tests with scaling factor of 150%





Dynamic earthquake tests

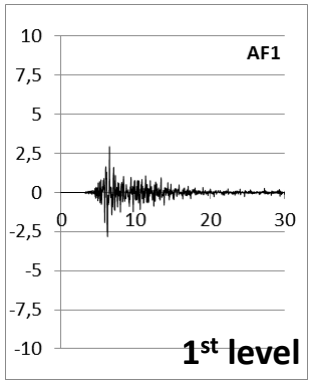
Damage phenomena

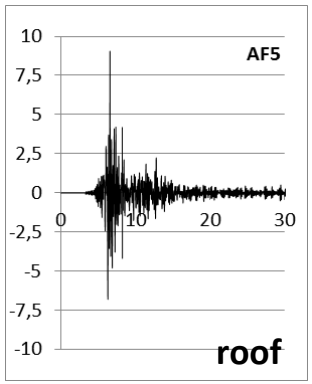
Visual inspection confirmed that **no damage** occurred in both structural and nonstructural elements for earthquake tests with scaling factor up to **100%,** whereas for higher intensities the inspections showed only the **detachment of cover paper at a corner joints.**

Detachment of cover paper at a corner joints

Acceleration amplification

The acceleration amplification was in the range from **1.15 to 2.23 for second floor** and from **1.63 to 3.10 for the roof**.

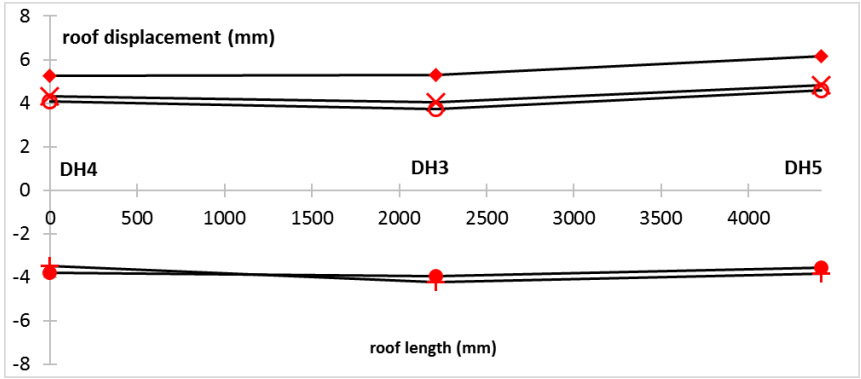




Accelerations in transversal direction recorded at the 1st level and roof

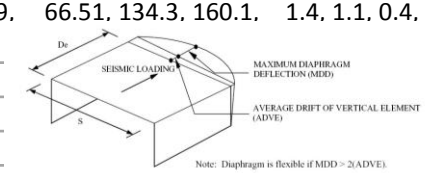
Diaphragms response

Roof diaphragm displacements obtained during the EA test with scaling factor of 10%



Recorded MDD and ADVE values

Test label	MDD (mm)	ADVE (mm)	MDD/ADVE (%)
EA_2_01, 2_02, 2_03, 2_04, 2_05, 2_06, 2_07, 2_08	0.07, 0.56, 0.73, 0.47, 0.70, 0.66, 0.89	3.04, 5.70, 7.85, 10.38, 13.38, 15.41, 21.80	2.3, **9.9,** 9.3, 4.6, 5.3, 4.3, 4.1
EA_3_01, 3_02, 3_03, 3_04, 3_05, 3_06, 3_07	0.21, 0.55, 0.67, 1.36, 0.87, 1.22, 0.26	11.18, 23.75, 28.79, 35.89, 45.34, 54.70, 64.82	1.9, 2.3, 2.3, 3.8, 1.9, 2.2, 0.4
EA_3_08	1.54	34.77	4.4
EA_4_01, 4_02, 4_03, 4_04	0.94, 1.51, 0.59, 1.09	66.51, 134.3, 160.1,	1.4, 1.1, 0.4,
EA_4_05	1.26		
EA_4_06	1.81		
EA_4_10	1.02		



Max **MDD/ADVE=0,099**: according to the ASCE 7 definition, **diaphragm can be assumed as rigid** in its plane

** Limit value (ASCE 7) for rigid diaphragms= 2,00*

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1. Introduction

2. Seismic design of CFS Constructions

3. Researches at the University of Naples Federico II

4. Case Study

5. Concluding Remarks

Building construction of foundation and primary stage school "BFS"

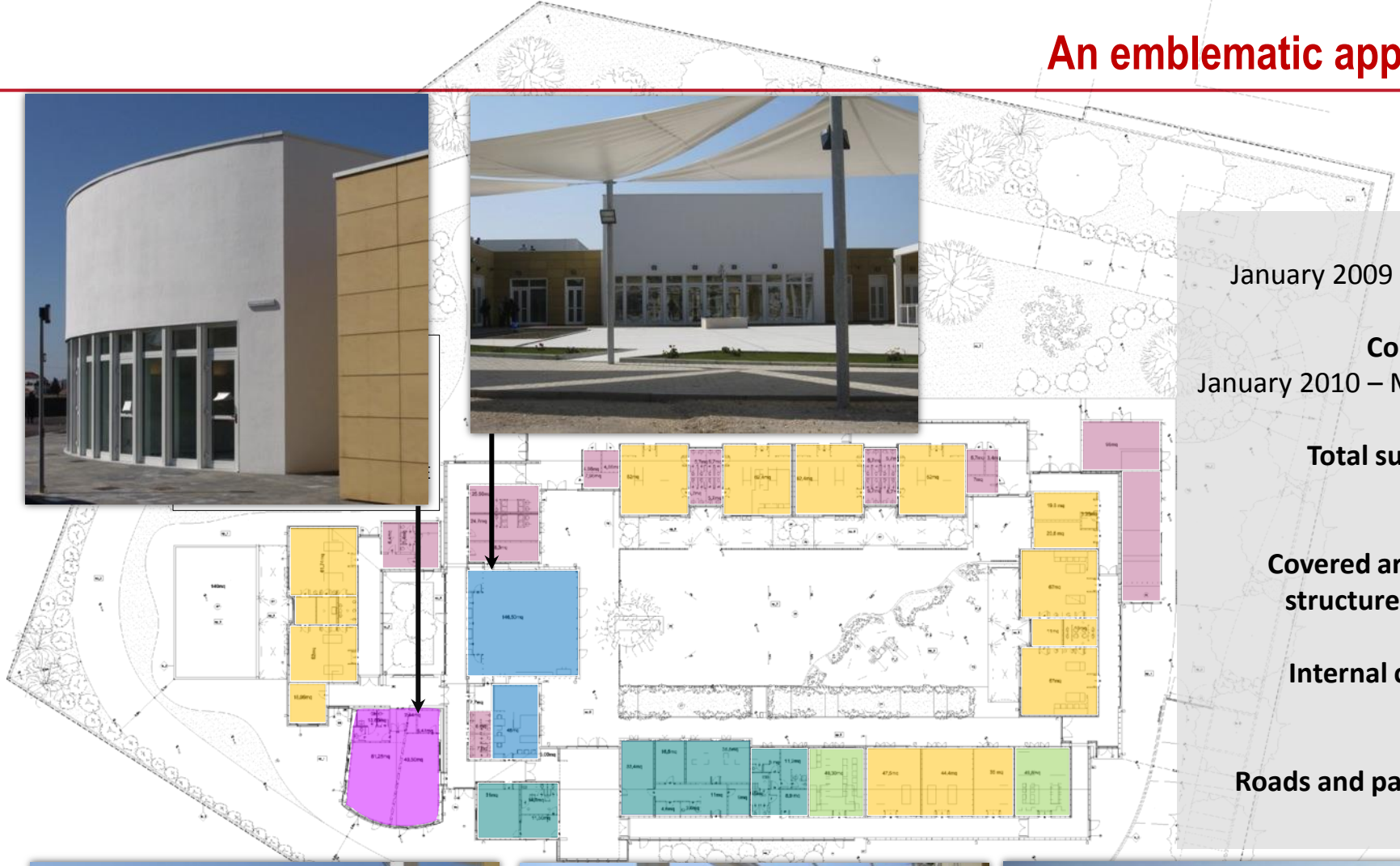
Lago Patria – Naples, Italy (2009-2011)

REQUIREMENTS

- BUILDING OF STRATEGICAL IMPORTANCE
- SHORT TIME
- HIGH PERFORMANCE IN TERMS OF:
  - SAFETY
  - DURABILITY
  - SEISMIC BEHAVIOUR
- ENVIRONMENTAL SUSTAINABILITY

FIRST IMPORTANT COLD-FORMED STEEL CONSTRUCTION WORK IN ITALY

An emblematic application



Design
January 2009 – July 2009

Construction:
January 2010 – March 2011

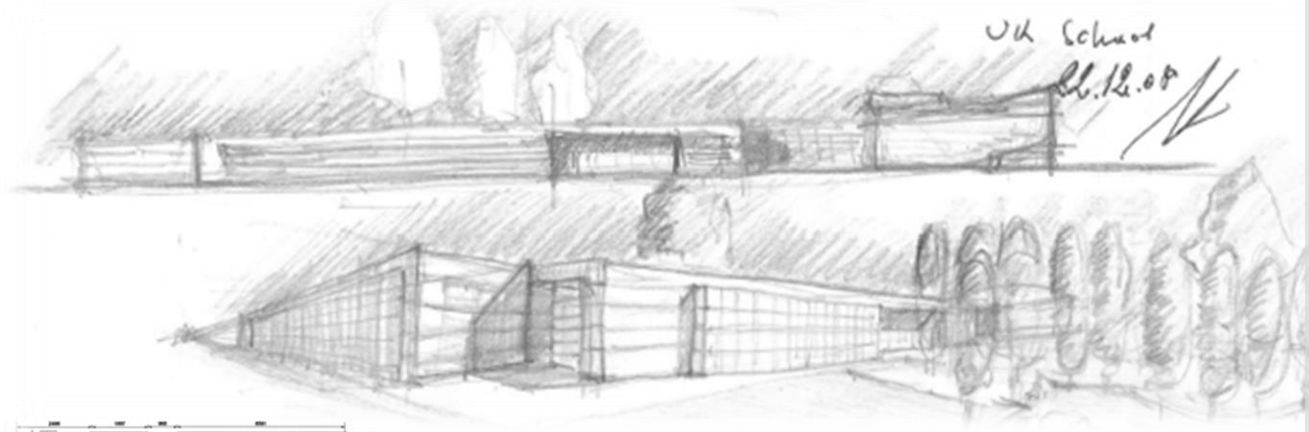
Total surface area:
15.850 m^2

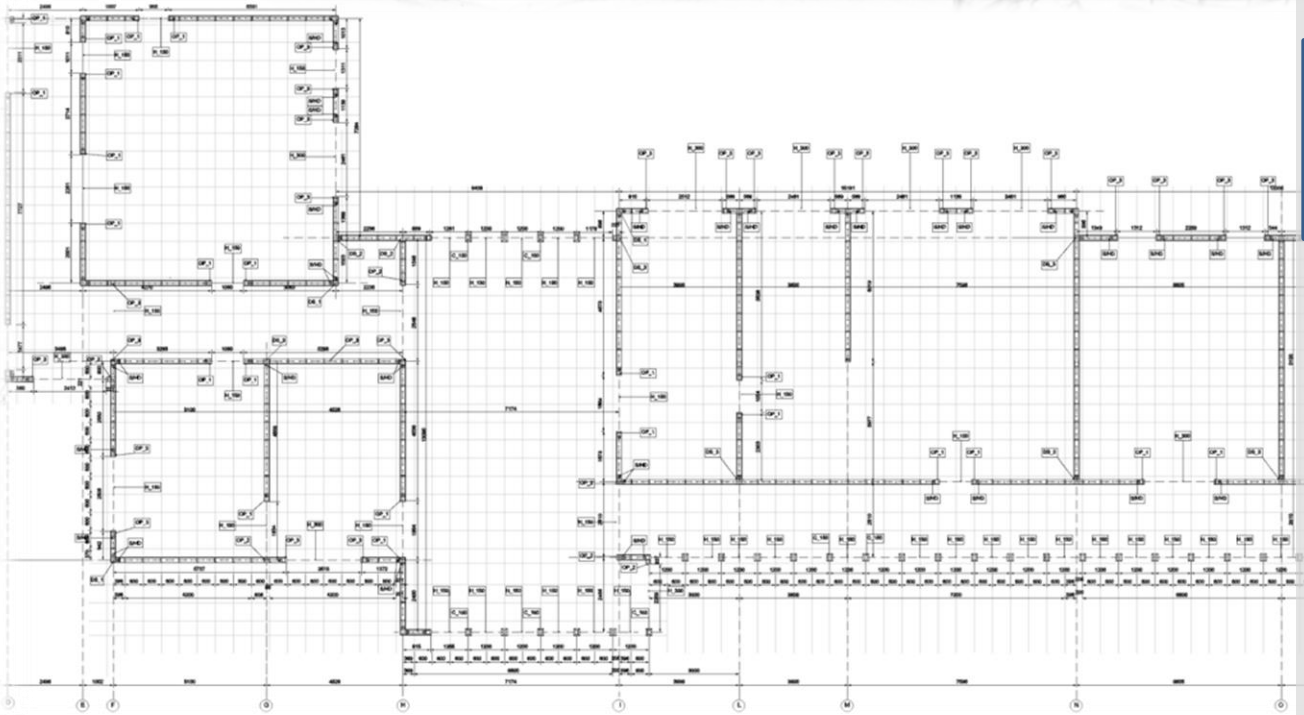
Covered area by steel structures: 3.000 m^2

Internal courtyards:
1.900 m^2

Roads and parking area:
3.700 m^2

An emblematic application





Owner:
Defense Estates UKNSU

Contractor:
COSAP

Architects:
Arch. Fiorenzo Petillo (*Team leader)*
Dr. Arch. Brigida Santangelo
Arch. Enza Terzigni

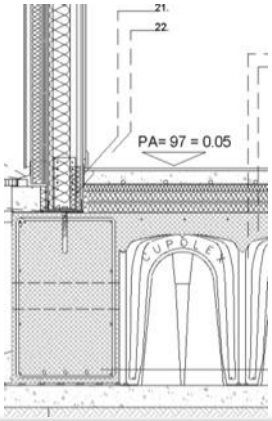
Structures:
Prof. Eng. Raffaele Landolfo
P.hD. Arch. Ornella Iuorio
P.hD. Eng. Luigi Fiorino

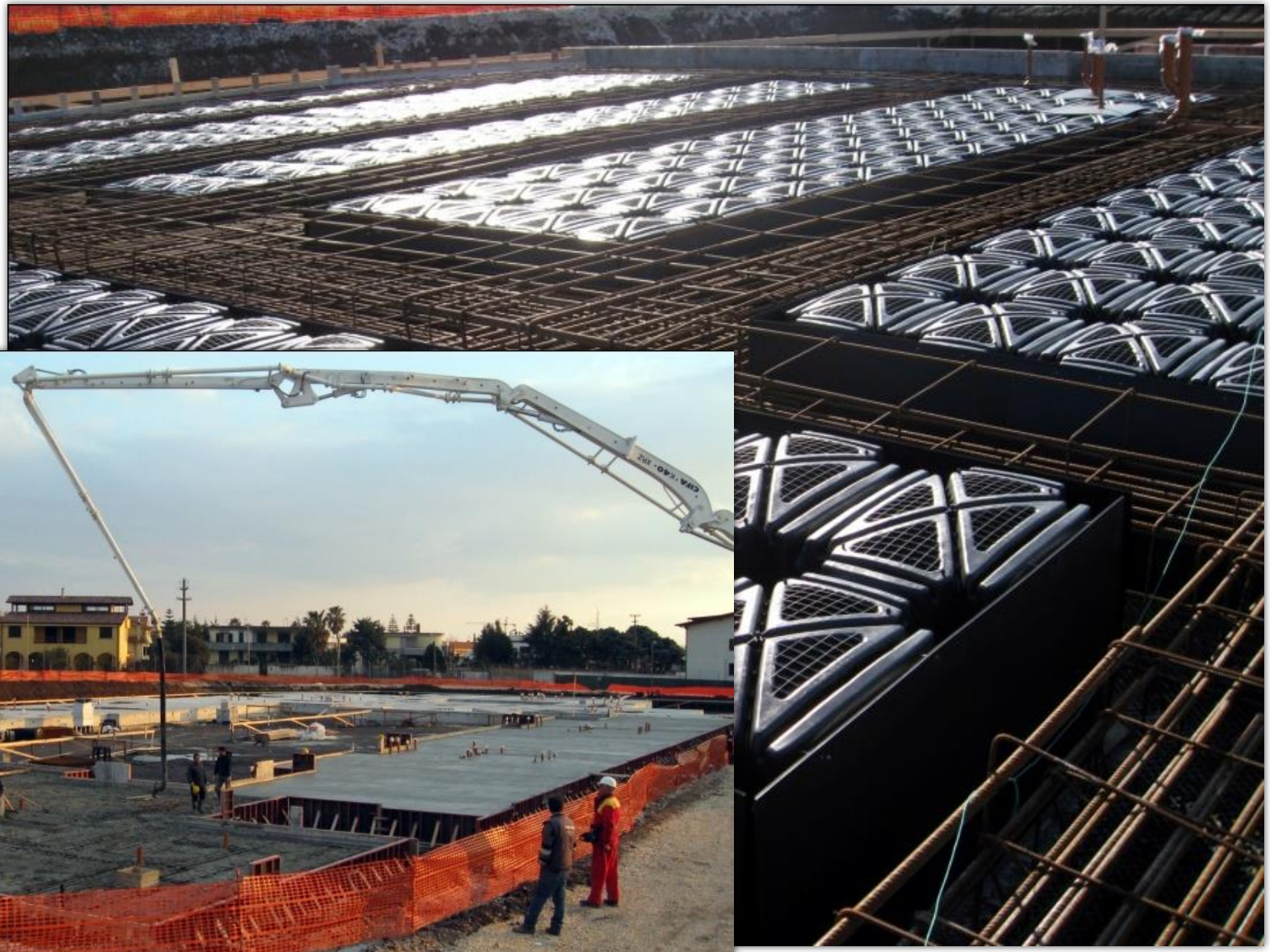
Technology:
Prof. Arch. Mario Losasso
Ass. Prof. Arch. S. Russo Ermolli
P.hD. Generosa Cacciapuoti
Arch. Antonio DAcunzi

M&E:
Eng. Roberto Romano

Accounting:
Arch. Alfonso Mauro

An emblematic application





Wall track

U153x50x20x1,5mm

Stud

C150x50x20x1,5mm

@600mm

OSB 9mm

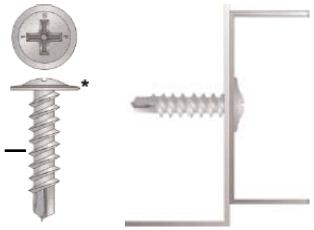
Wall flat strap

Shear anchors HST 20

HOLD DOWN S700 steel grade

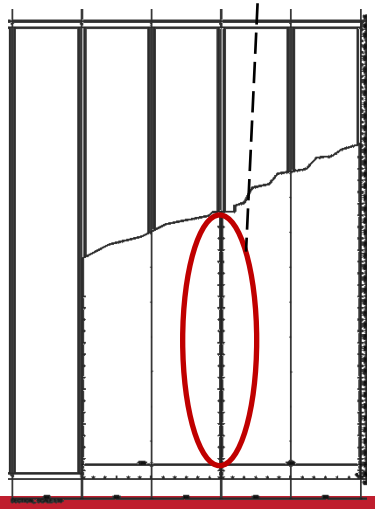
HIT-RE 500+HAS-E(5.8)-M24

STEEL –TO – STEEL CONNECTIONS:



CFS profiles – TO – 9mm OSB
CONNECTIONS:
Flat head self drilling screws

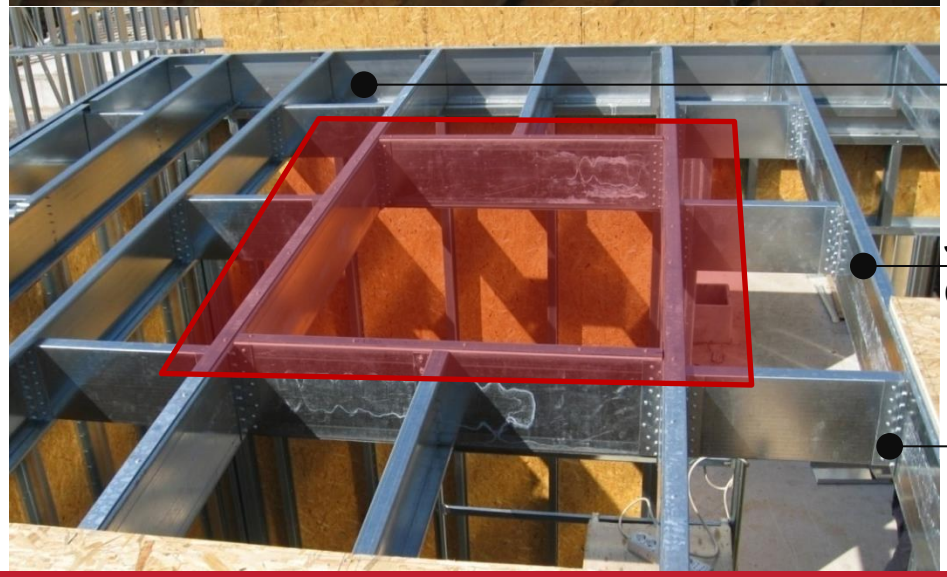
“CH 01 42 025”



OSB 18mm

Flat strap
50x1,5mm
@ 1200 o 2400mm

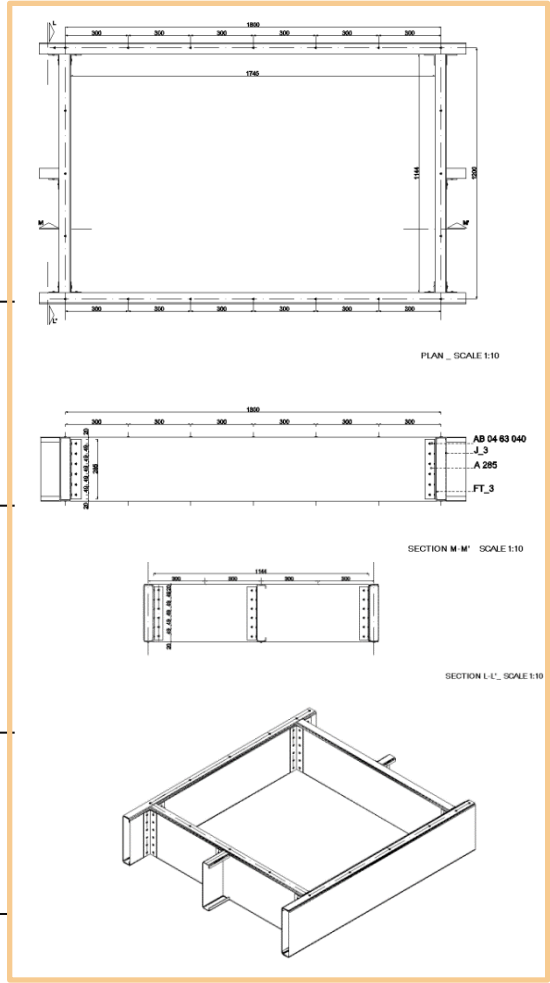
Blocks
250x50x20x1,5
@ 1800 o 3000mm



Floor track
U 303x50x1,5 - 3mm

Joist
C 300x50x20x1,5 - 3mm

Web stiffner



An emblematic application

An emblematic application

BFS School: an emblematic application

An emblematic application

Total surface area:
15.850 m^2

Covered area by steel structures:
3.000 m^2

TOTAL TONNAGE:
140 tons of steel

Weight per square meter:
0.45 kN/m^2

OSB 9 mm (WALLS):
10000 m^2

OSB 18mm (FLOORS:
3000 m^2

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1. Introduction

2. Seismic design of Lightweight CFS Constructions

3. Researches at the University of Naples Federico II

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Conclusions

- The Lightweight Steel-Framed Constructions are **very competitive** in the contemporary markets for the lightness, high structural efficiency, high structural performance, dry realization, recyclable nature

- **High levels of prefabrication, safety, durability and sustainability** are spreading these construction systems all over the world.

- Furthermore, **high seismic performance** even in case of strong ground motions characterize these systems.

- The current trend of the construction market leads toward **integrated solutions** that must satisfy multiple requirements in terms of eco-efficiency, structural performance, without neglecting the economic aspects.

- The **actual lack in specific design codes**, mainly for the applications in seismic area, requires the development of new research in the field.

- The research and applications developed at the University of Naples Federico II demonstrated the competiveness of Lightweight Steel-Framed Constructions in seismic zone.

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Thanks for your kind attention

Evento HILTI
Unicredit Pavilion,
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Milano, 24 ottobre 2017