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The design assisted by testing:

a research project of a cold-formed steel building system

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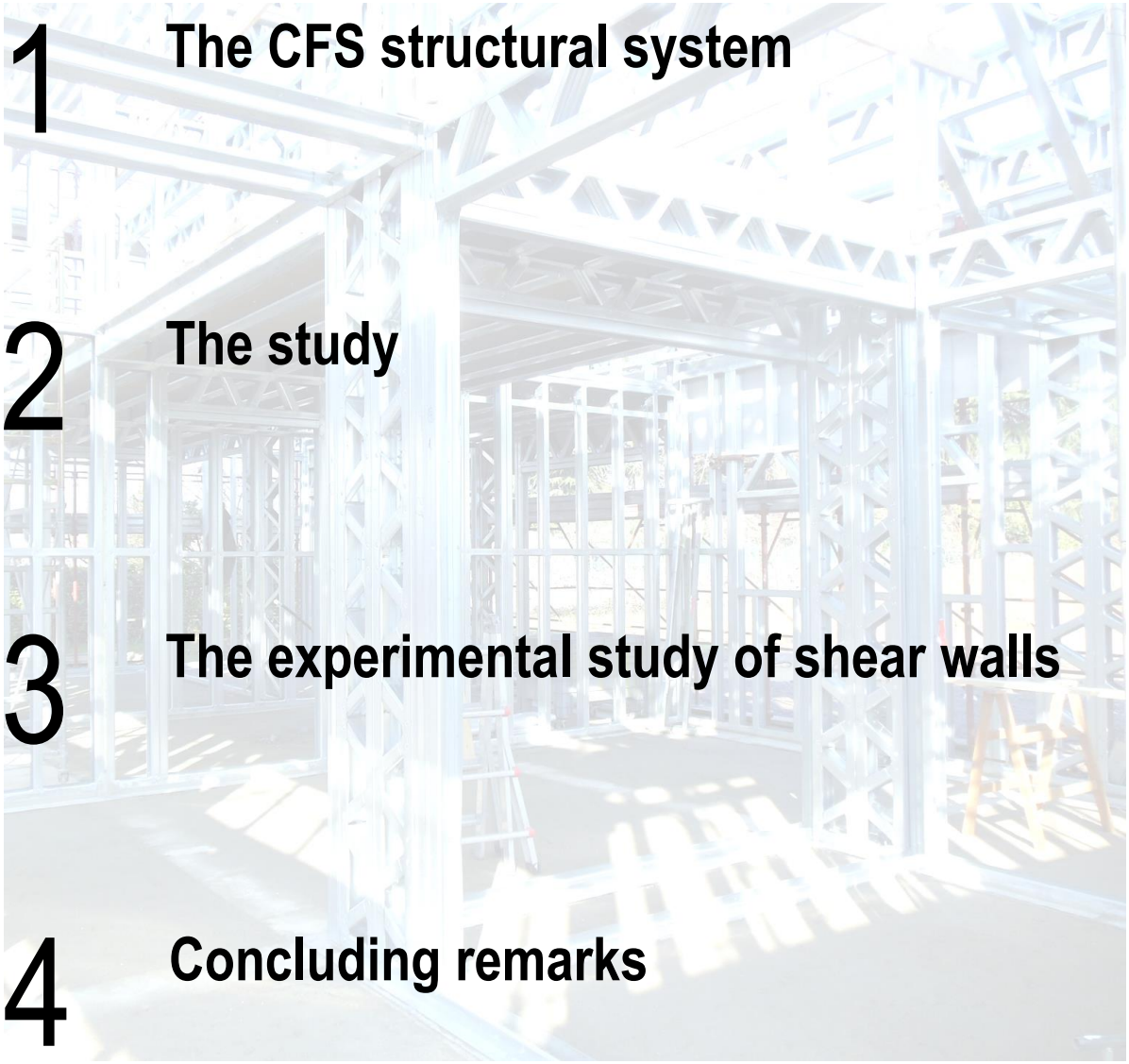


1 **The CFS structural system** — reference standards

2 **The study** — experimental program on 2D and 3D subassemblies

3 **The experimental study of shear walls** — the outcomes

4 **Concluding remarks**

COLD-FORMED STEEL BUILDING

The reference standards		
NTC 2008 + Circolare n.617/2009	UNI EN 1998-1:2013	UNI EN 1993-1-8:2005
UNI EN 1990:2006	UNI EN 1993-1-1:2014	UNI EN 1993-1-3:2007

'Design assisted by testing'

5.2 Design assisted by testing - [EN 1990]
(1) Design may be based on a combination of tests and calculations.
NOTE Testing may be carried out, for example, in the following circumstances:
– if adequate calculation models are not available;
– if a large number of similar components are to be used;
– to confirm by control checks assumptions made in the design. See Annex D.

2.5 Design assisted by testing - [EN 1993-1-1]
(1) The resistances Rk in this standard have been determined using Annex D of EN 1990.

9 Design assisted by testing - [EN 1993-1-3]
(1) This Section 9 may be used to apply the principles for design assisted by testing given in EN 1990 and in Section 2.5. of EN 1993-1-1, with the additional specific requirements of cold-formed members and sheeting.
(2) Testing should apply the principles given in Annex A.

THE EXPERIMENTAL PROGRAM

- Thin-walled cold-formed sections usually adopted tend to be very **slender** both globally and in the cross-sectional components;
- They are **subject to global, local and distortional instability**, as well as to their interactions;
- **Buckling** reduces the members' load capacity, and makes **design burdensome**, due to the need of incorporating it;
- The **design** of these structures is **fairly complex**;
- When developing an industrial prefabricated system, it is feasible and effective to study building components at different level of complexity from the individual members to 2D and 3D sub-structures;
- Design also should aim at developing **efficient connection** both in terms of static performance, of fabrication costs, and of easiness of assembling.

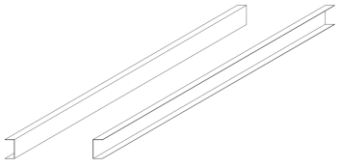
Characterization of C-sections

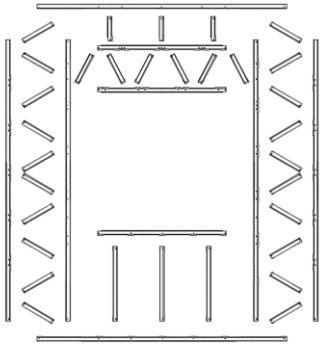
Characterization of subassemblies

Wall

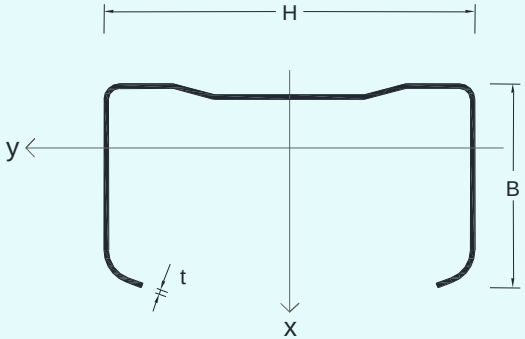
Ancillary tests characterization of :
- sheathing panels
- sheathing to framing connections

CHARACTERIZATION OF C-sections



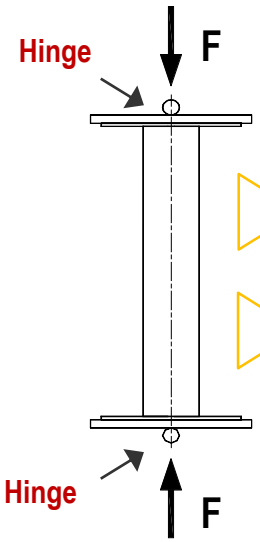


Section



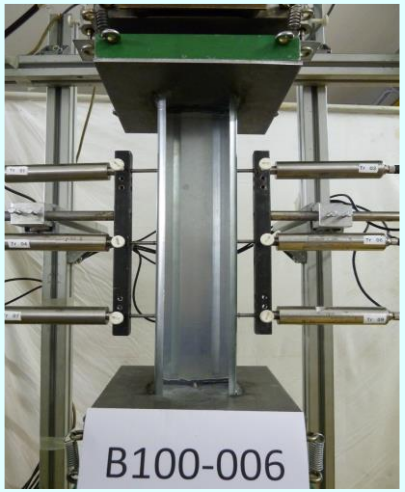
Geometry	
H	100 – 150 – 200 mm
B	57 mm
t	1 – 1.2 mm

CHARACTERIZATION OF C-sections



Test set-up

Test set-up



Test set-up

Test set-up

Compression tests

(in agreement with EN 1993-1-3)

Parameters investigated:

- C-section's depth;
- C-section's thickness;
- Specimen's length

90 TESTS

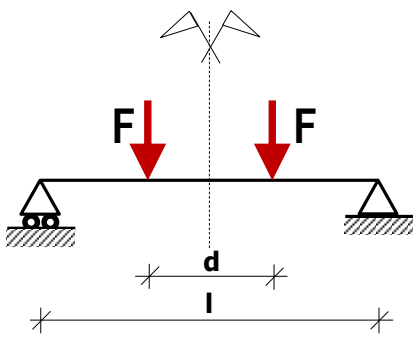
OUTPUT OF THE TESTS

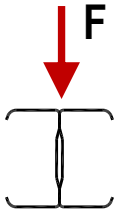
Effective area

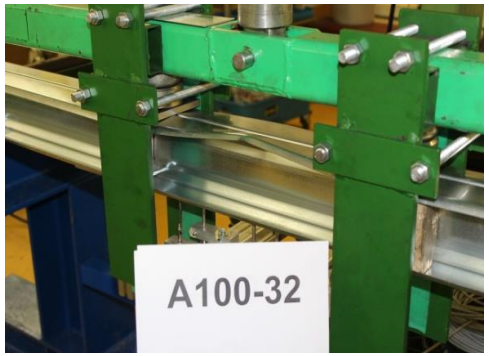
Collapse load

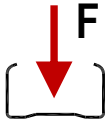
Failure mode

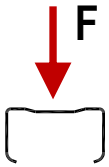
CHARACTERIZATION OF C-sections











Bending tests
(in agreement with EN 1993-1-3)

Parameters investigated:

- C-section's depth;
- C-section's thickness;
- Specimen's length

211 TESTS

OUTPUT OF THE TESTS

Collapse load

Failure mode

CHARACTERIZATION OF SUBASSEMBLIES - WALLS

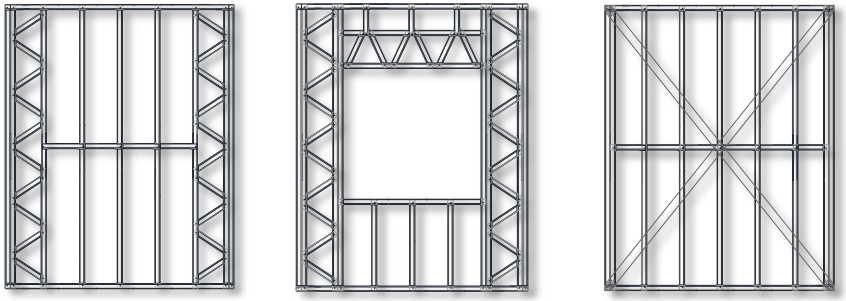
Shear wall

Transfer to the foundations:

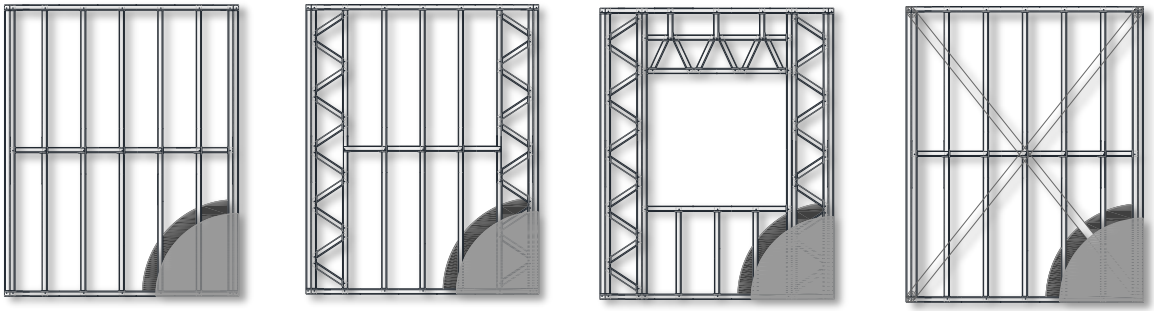
the **vertical loads**
of the flooring system

the **horizontal loads**
due to wind and earthquake

CHARACTERIZATION OF SUBASSEMBLIES - WALLS



without "skin"



with "skin"

Shear tests

Parameters investigated:

- Wall type (with or without opening);
- Bracing systems (trussed frame or diagonal straps);
- Influence of "skin"

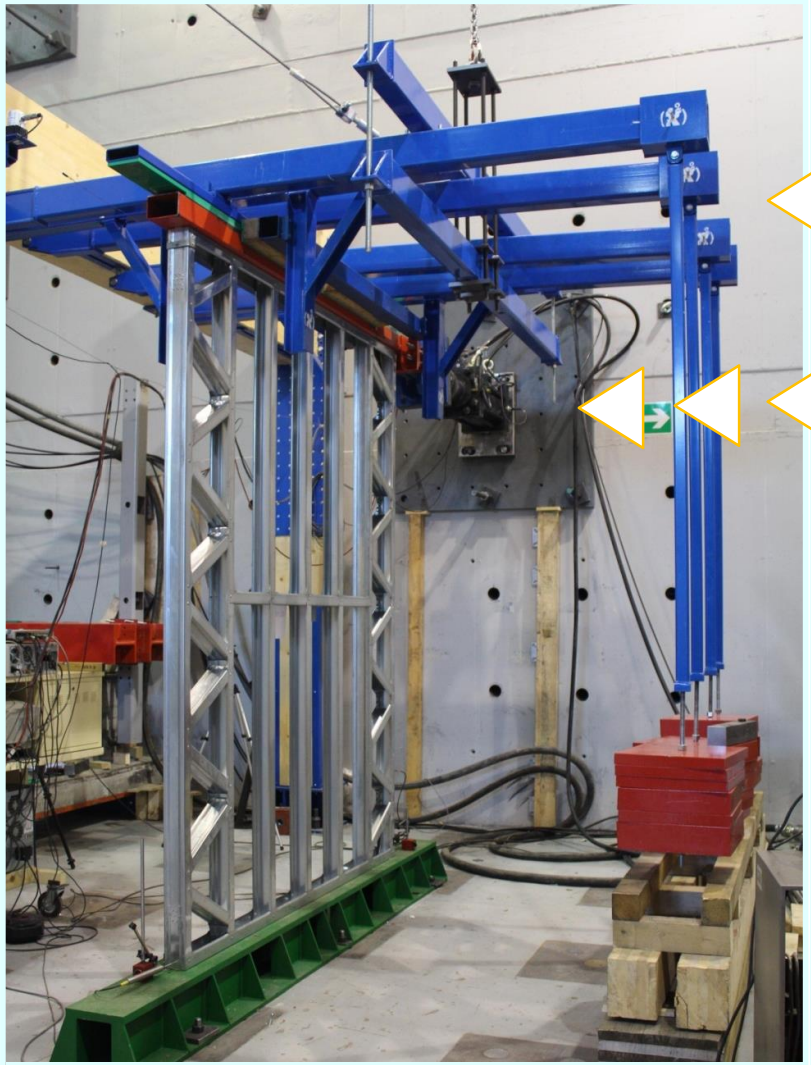
21 TESTS

OUTPUT OF THE TESTS

Collapse load

Failure mode

CHARACTERIZATION OF SUBASSEMBLIES - WALLS



Test set-up

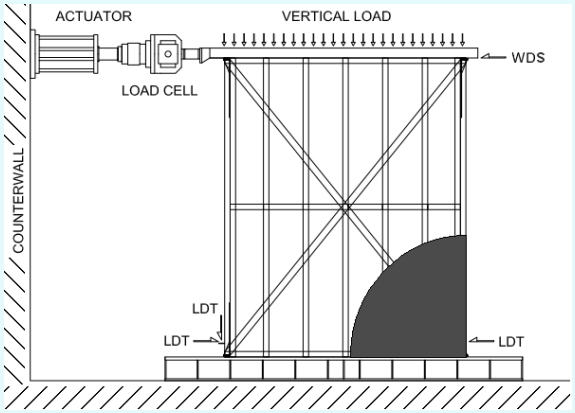
Vertical load

(17,07 kN/m)

Horizontal load

Shear tests

Set-up:



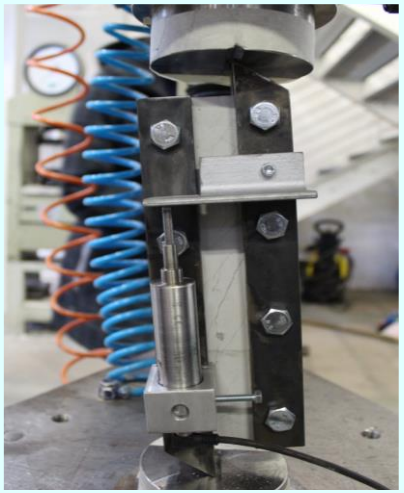
allows perform tests in

MONOTONIC regime

and

CYCLIC regime

ANCILLARY TESTS



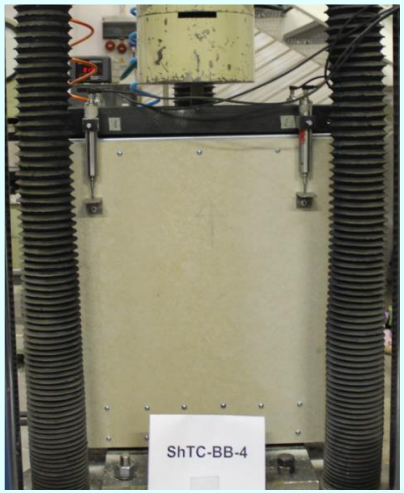
Test set-up

The specimen – after test

Shear test on Sheathing panels

Parameters investigated:

- Shear modulus **G**;
- Shear stress τ.



Test set-up

Test set-up

Tension test Fastners (sheathing to frame)

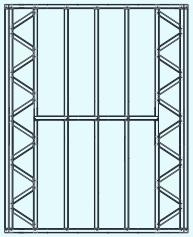
Parameters investigated:

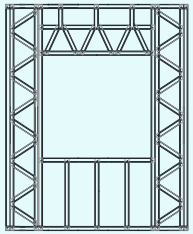
- Stiffness of fasteners;
- Ultimate resistance of fasteners.

MEASURED RESPONSE

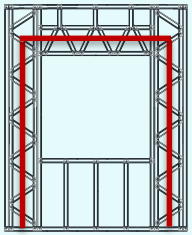
Specimen	Loading protocol	Positive Load			Negative load		
		Secant Stiffness 40% F_{ult}	Ultimate Resistance F_{ult}	Drift at Ultimate Resistance	Secant Stiffness 40% F_{ult}	Ultimate Resistance F_{ult}	Drift at Ultimate Resistance
		kN/m	kN	mrad	kN/m	kN	mrad
G6 100 400 XX-1	Monotonic	261	12,560	36,4	-	-	-
G6 100 400 XX-2	Cyclic	280	14,920	36,5	317	-14,960	-36,6
G7 100 400 XX-1	Cyclic	429	**14,240**	**28,4**	606	-14,880	-24,3
G9 100 400 XX-1	Monotonic	2361	**35,920**	**40,9**	-	-	-
G9 100 400 XX-2	Cyclic	2356	35,840	31,5	2388	-39,520	-25,6

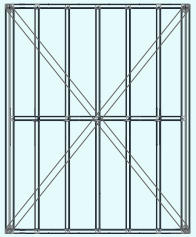
Wall type
(without "skin")





"frame" behavior



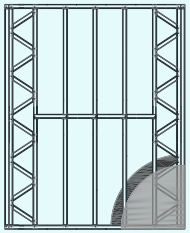


best performance:
- stiffness
- resistance

MEASURED RESPONSE

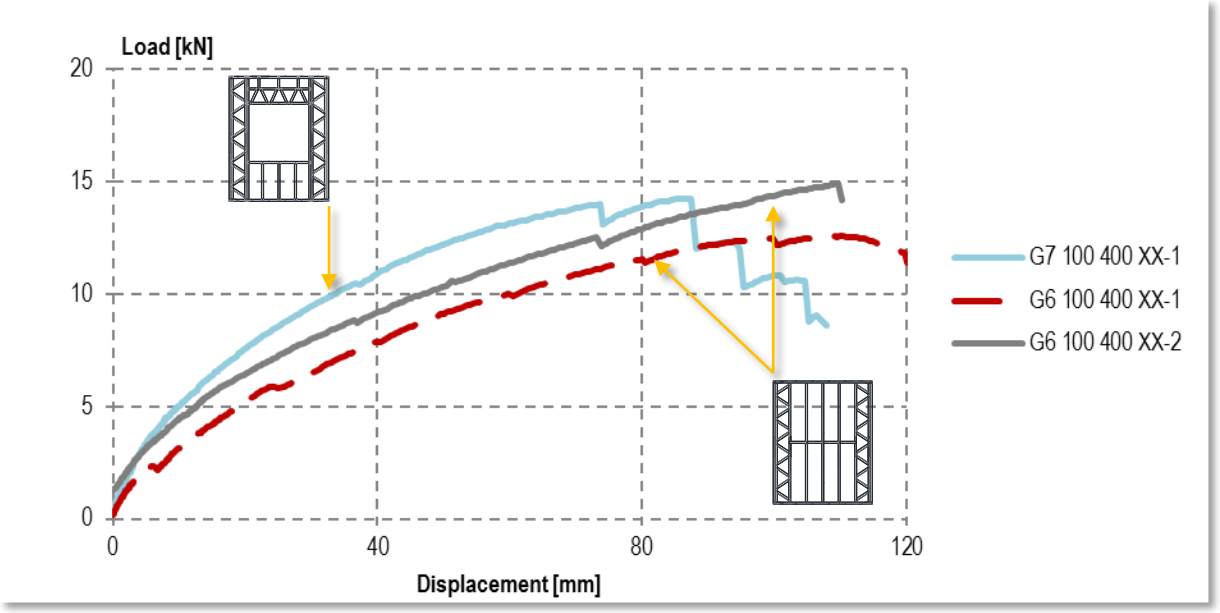
Specimen	Loading protocol	Positive Load			Negative load		
		Secant Stiffness 40% F_{ult}	Ultimate Resistance F_{ult}	Drift at Ultimate Resistance	Secant Stiffness 40% F_{ult}	Ultimate Resistance F_{ult}	Drift at Ultimate Resistance
		kN/m	kN	mrad	kN/m	kN	mrad
G5 100 400 BB-1	Monotonic	6760	64,200	**9,7**	-	-	-
G5 100 400 BB-2	Cyclic	5639	**62,720**	10,3	5535	-60,600	-10,1
G8 100 400 EF-1	Monotonic	6044	70,040	17,3	-	-	-
G8 100 400 EF-2	Cyclic	5463	66,800	10,8	5254	-68,880	-10,6
G9 100 400 GH-1	Monotonic	5320	**76,920**	13,3	-	-	-
G9 100 400 GH-2	Cyclic	3824	70,760	**18,0**	2769	-67,120	-14,1

Wall type
(with "skin")

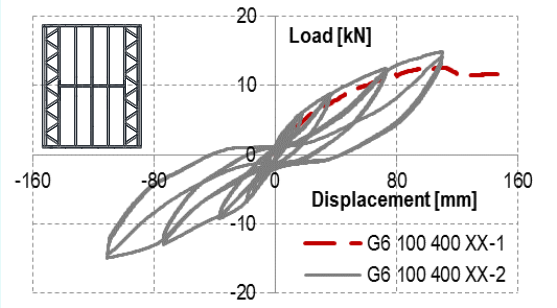


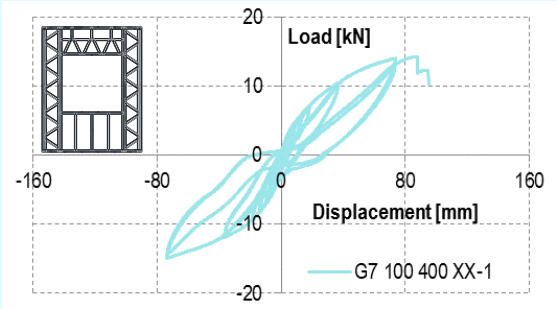
Comparable results:
the steel bracing system type did not influence substantially
the stiffness or
the ultimate load capacity

COMPARISON



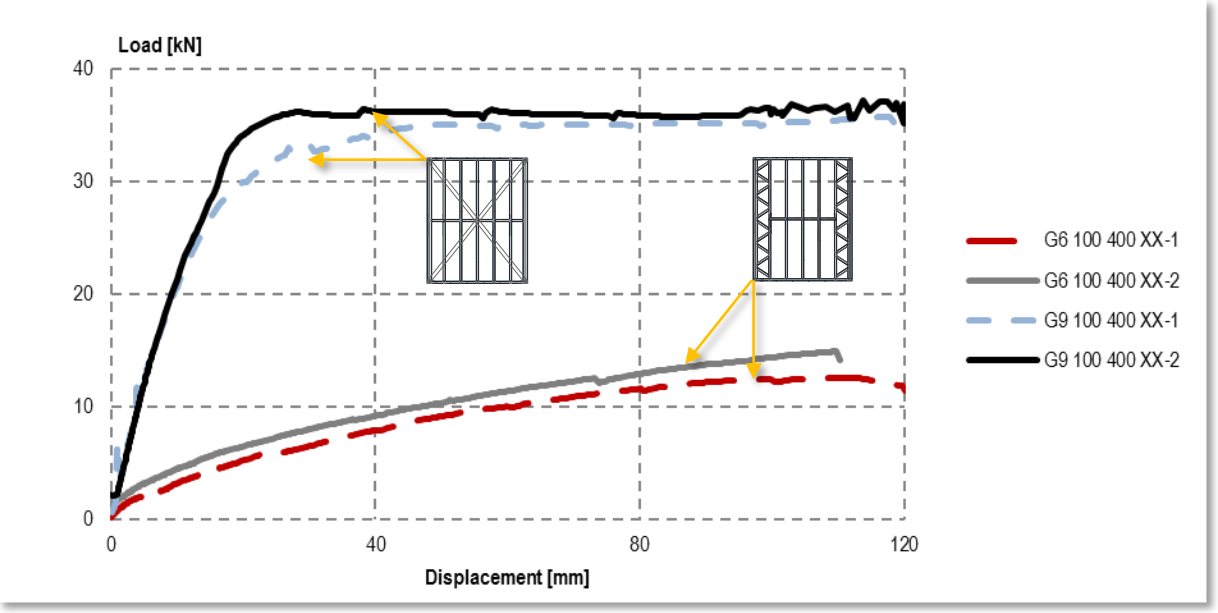
Influence of opening



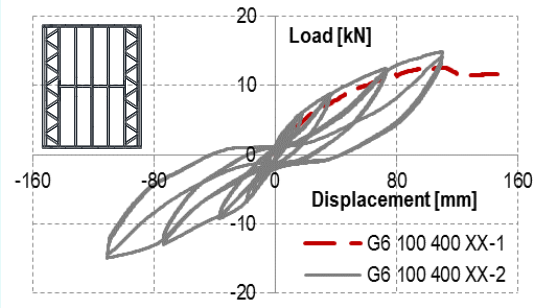


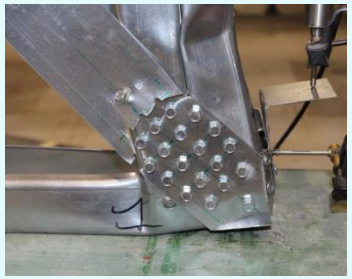
- A window opening does not affect negatively the wall performance. It was observed: in **cyclic tests** ➡ **clear increase of the stiffness**;
- The presence of an opening requires a strengthening of the transversal link between the chords, which explains the enhancement of the wall performance.

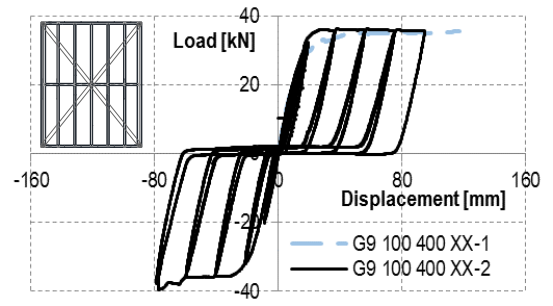
COMPARISON



Bracing system





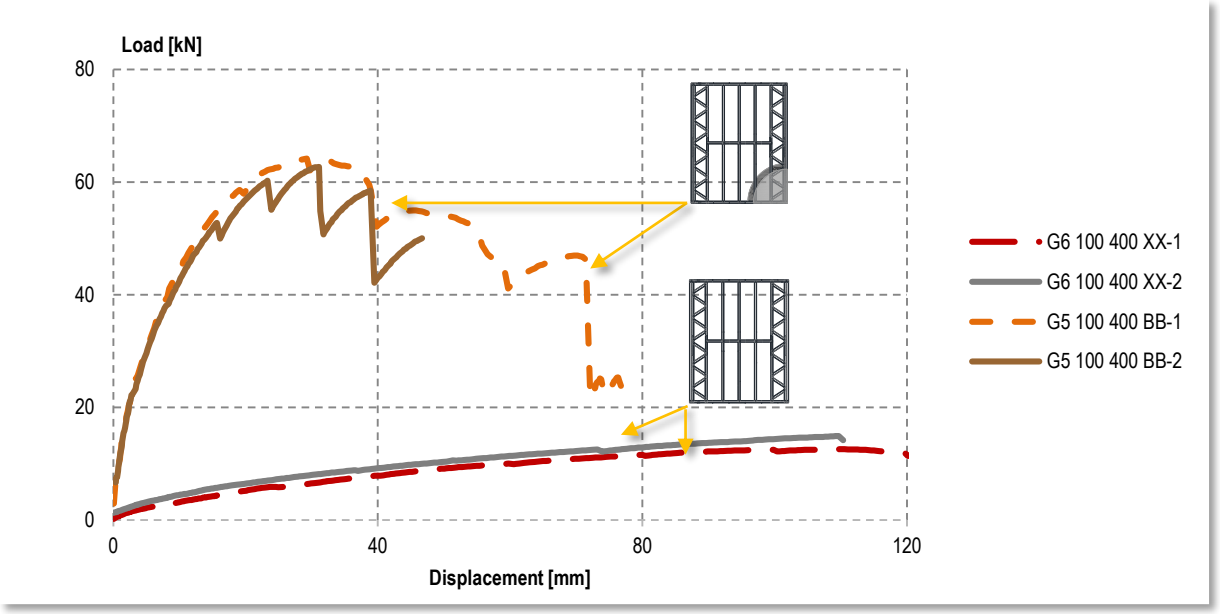


- Strap bracing systems greatly enhance the wall response;
- If G6 100 400 XX assumed as reference case: an **increase of 805% and 186%** of stiffness and resistance, respectively, was achieved in monotonic tests;
- Different collapse modes were observed:

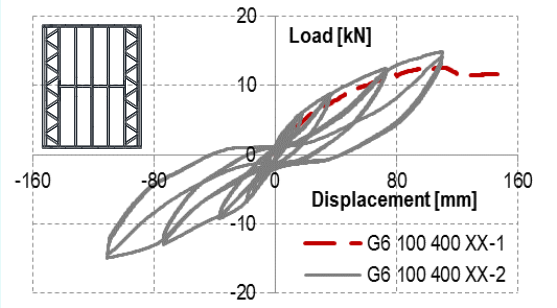
strap bracing wall ➡ **collapse of the strap** at the connection with the chord

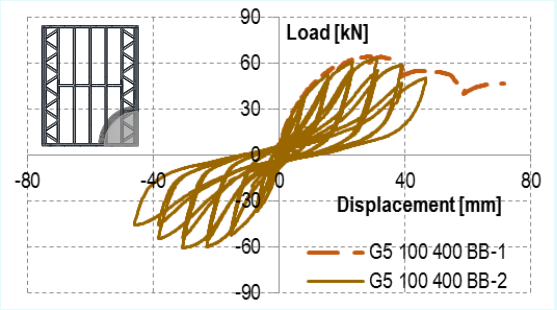
trussed bracing wall ➡ **local deformation** at the chords ends with rivets pull-out

COMPARISON



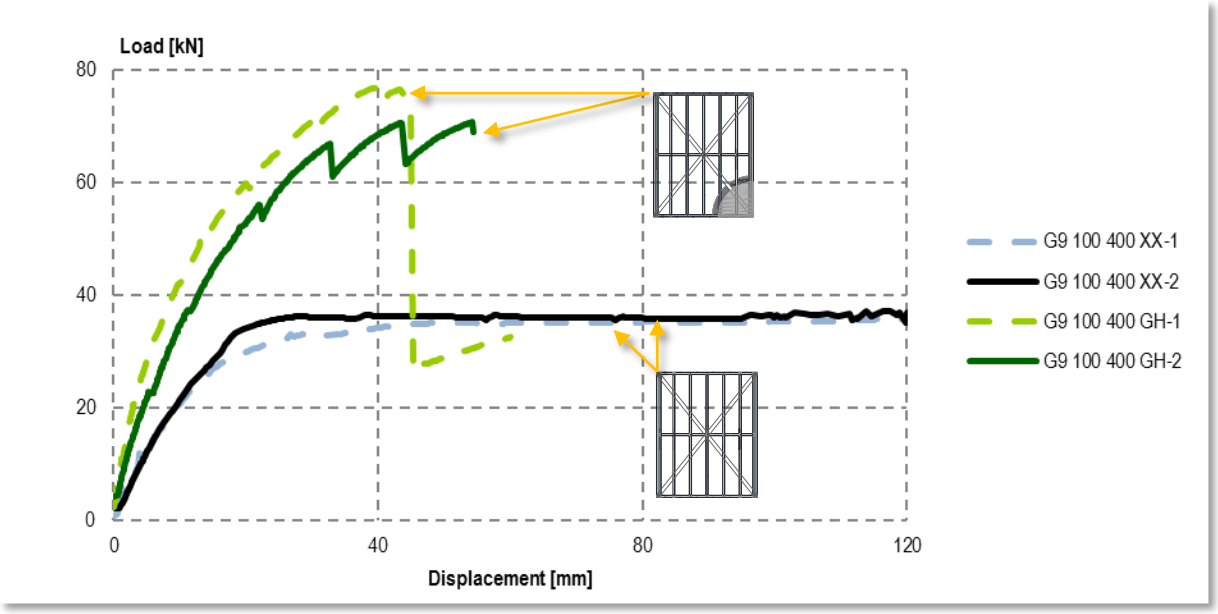
Influence of the "skin"





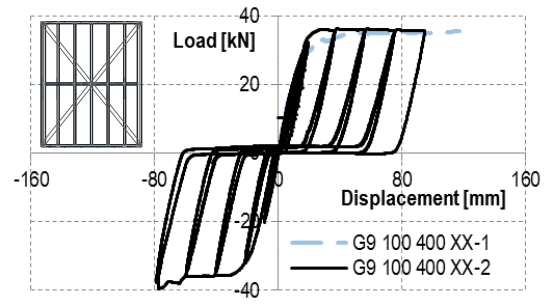
- The "skin" increased the resistance and the stiffness of the wall;
- If G6 100 400 XX is assumed as reference case, an **increase of 2490% and 399%** of stiffness and resistance, respectively, was achieved in monotonic tests;
- Specimens G6 have much more ductility compared to specimens G5

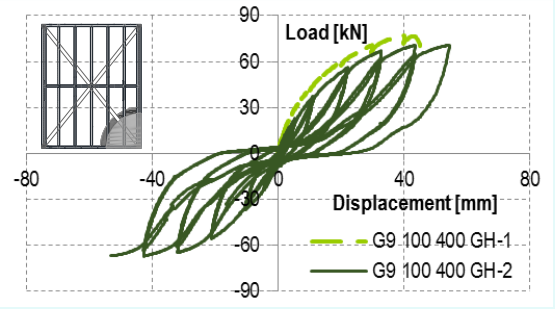
COMPARISON



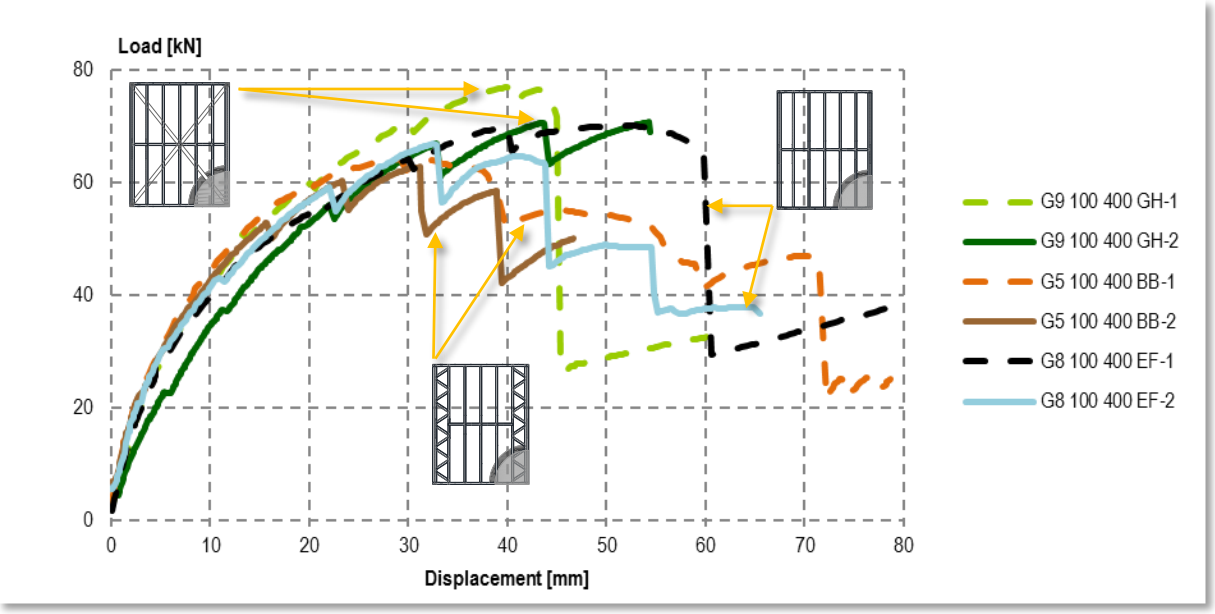
- The "skin" increased the resistance and the stiffness of the wall;
- If G9 100 400 XX is assumed as reference case, an **increase of 125% and 114%** of stiffness and resistance, respectively, was achieved in monotonic tests;
- Collapse of the test of the wall with skin was due to the **collapse of the bolt of the hold-down**;
- The sudden collapse of the wall prevents the evaluation of the wall performance in terms of ductility.

Influence of the "skin"



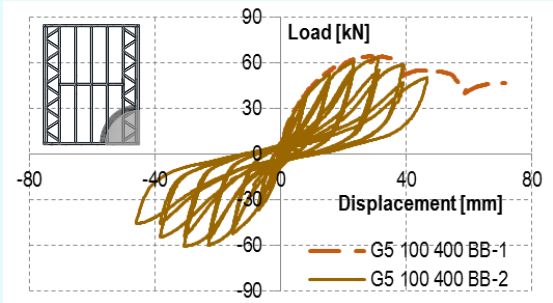


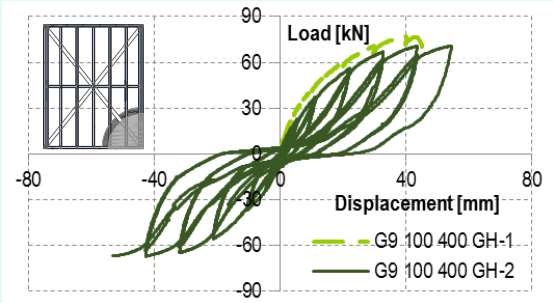
COMPARISON

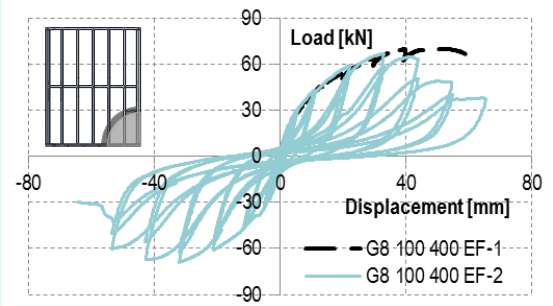


- The selection of **steel bracing system** (trussed bracing or strap bracing) **seems not to affect in a significant way** the wall response in terms of initial stiffness and collapse load;
- The **mechanical properties of the "skin"** materials on the other end can affect significantly the **deformation capacity**.

Influence of the "skin"







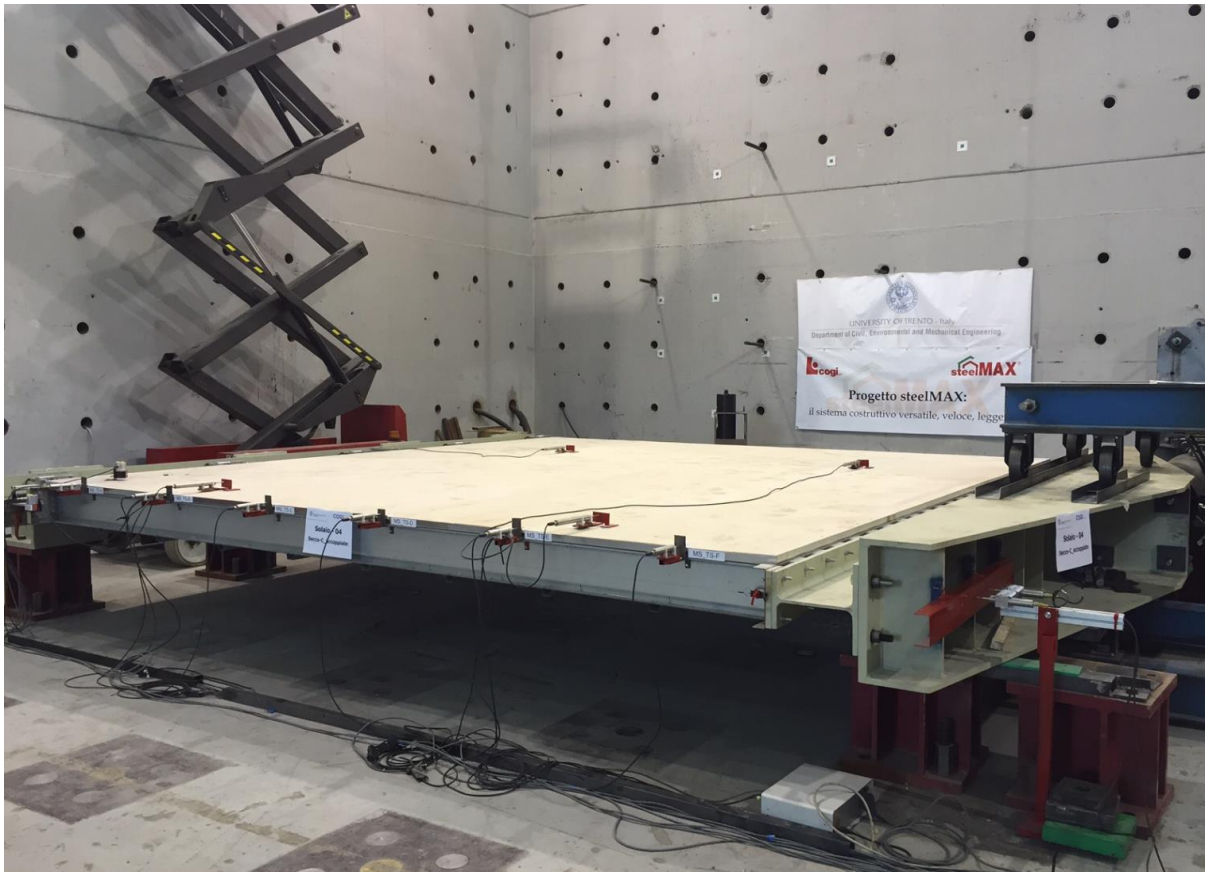
THE DESIGN ASSESTED BY TESTING

The goal of the study was the characterization of the **building system**. In the framework activities the University of Trento was involved in the **experimental** and in the **numerical** studies. Parallel to this Cogi studied the **technological-productive** aspects for development of the building system.

In particular this presentation was focused in the experimental study of the walls. The outcomes showed that:

- The performance of the walls with diagonal bracing is the best under all aspects.
- The "skin" can provide also an important bracing action. It substantially contributes by itself to the lateral response, as clearly shown by specimens G8, whose steel framing is characterized by absence of any bracing.
- The performance achieved by the tested shear walls allow **a competitive building system**, which is adequate for use in seismic zones.

CHARACTERIZATION OF COLD-FORMED STEEL DIAPHRAGMS



Shear tests

Thanks
for your attention!

steelMAX®

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