ASSOBETON

Seismic design of precast structures: a quick overview from the Italian manufacturers point of view

Antonella Colombo

4 February 2022

Italian Design codes

National law or Eurocodes?

… *As example of countries, where there are no conflicting standards, but the existing national regulations introduce directly design rules which do not fully reflect the entire set of the Eurocodes provisions, one can mention Italy,…* (*The implementation of the Eurocodes in the National Regulatory Framework – JRC technical reports 2019*)

- Norme Tecniche per le Costruzioni (DM 17/01/2018)
- Circolare n.7/2019

NTC 2018 - ToC

368 pages

Chapter 1 - Scope

Chapter 2 - Principles and Requirements for the safety, serviceability, …

Chapter 3 - Actions on structures

Chapter 4 - Design of (concrete, steel, timber, mansonry, …) structures

Chapter 5 - Bridges

Chapter 6 – Geotechnical design

Chapter 7 – Seismic design

Chapter 8 – Existing structures

Chapter 9 – Acceptance criteria for structures

Chapter 10 - Drafting of structural projects and calculation reports

Chapter 11 - Qualification, certification and acceptance of materials and products for structural use

Chapter 12 – Technical references


GAZZETTA UFFICIALE
DELLA REPUBBLICA ITALIANA
PARTE PRIMA
MINISTERO DELLE INFRASTRUTTURE E DEI TRASPORTI
DECRETO 17 gennaio 2018.
Aggiornamento delle «Norme tecniche per le costruzioni».

NTC 2018 – Chapter 1

This document defines the principles for the design, execution and testing of constructions, with regard to the performance required in terms of essential requirements of mechanical resistance and stability, even in the case of fire, and durability.

It therefore provides the general safety criteria, specifies the actions that must be used in the design, defines the characteristics of materials and products and, more generally, deals with aspects relating to the structural safety of the works.

Regarding the indications for obtaining the prescribed performances, if not expressly specified in the document, reference can be made to standards of proven validity and other technical documents listed in Chapter 12. In particular indications provided by the Eurocodes with the relative National Annexes constitute indications of proven validity and provide the systematic application support of NTC 2018.

Circolare n.7 - ToC

Circolare n.7 aims to provide clarifications, indications and additions, for an easier and more unambiguous application of the NTC.

Same ToC as NTC2018.

337 pages


Supplemento ordinario alla "Gazzetta Ufficiale", n. 35 del 11 febbraio 2019 - Serie generale

GAZZETTA UFFICIALE
DELLA REPUBBLICA ITALIANA

PARTE PRIMA — Roma - Lunedì, 11 febbraio 2019

N. 5

MINISTERO DELLE INFRASTRUTTURE
E DEI TRASPORTI

CIRCOLARE 21 gennaio 2019, n. 7 C.S.LL.PP.

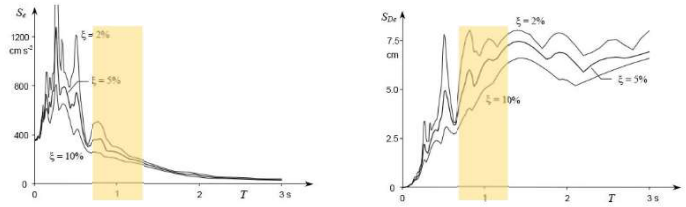
Istruzioni per l'applicazione dell'«Aggiornamento delle "Norme tecniche per le costruzioni"» di cui al decreto ministeriale 17 gennaio 2018.

What we learned from the past

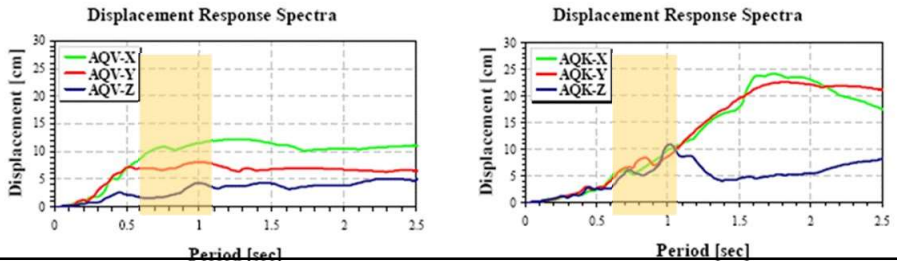
- Tolmezzo earthquake 1976
- L'Aquila earthquake 2009
- Emilia earthquake 2012
- Centro Italia earthquake 2016
- Research project (SAFECAST-SAFECLADDING)

Forces vs deformations

Tolmezzo 1976



L'Aquila 2009



Supports

Emilia 2012



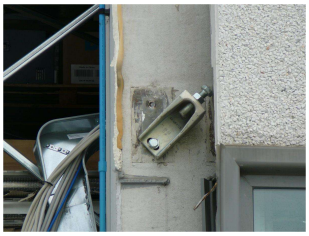
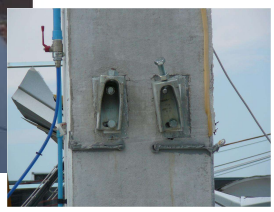


Ductility

Panels

Emilia 2012



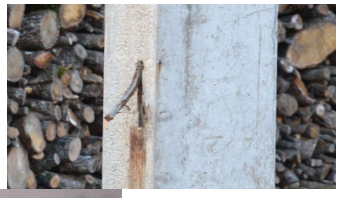
Non-loaded columns

L'Aquila 2009

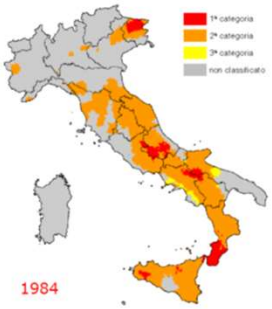


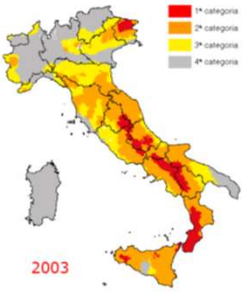
Connections

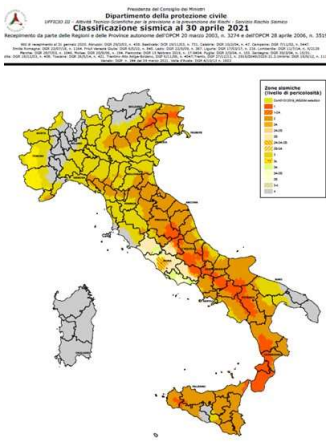
Centro Italia 2016



Identification of seismic areas

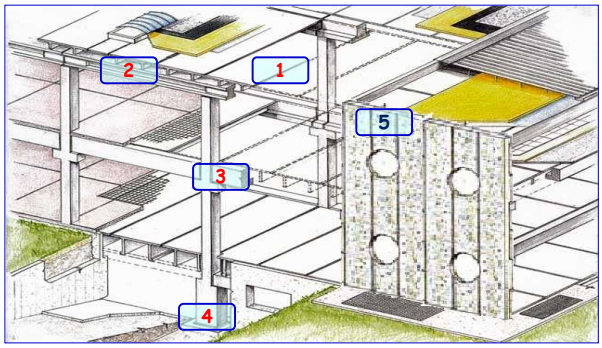




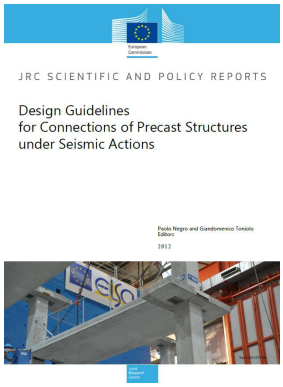


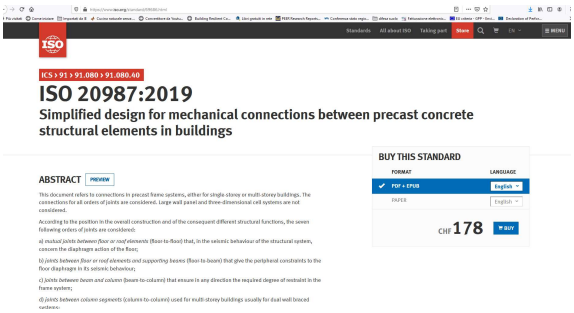
SAFECAST

Performance of Innovative Mechanical Connections
in Precast Building Structures under Seismic Conditions



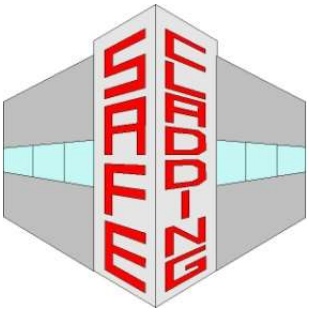
ISO 20987:2019



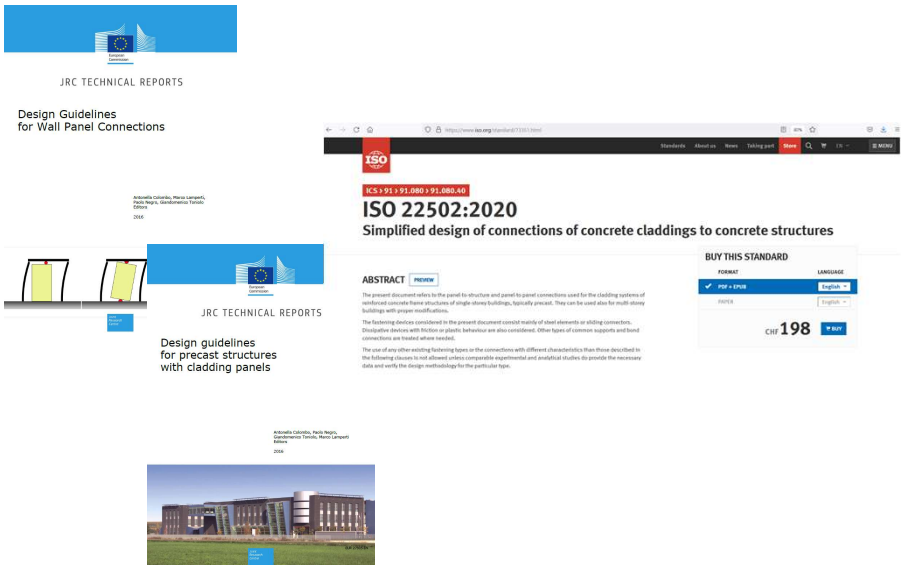


SAFECLADDING

Improved fastening systems of cladding wall panels of precast buildings in seismic zones



ISO 22502:2020

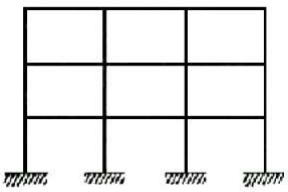


NTC 2018 – Chapter 7

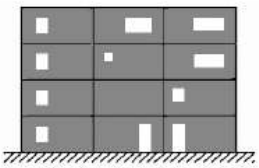
- Structural types
- Behaviour factor
- Structural modelling
- Connections
- Panels

Structural types

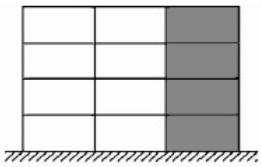
7.4.3.1 For concrete structures



Moment resisting frame structures

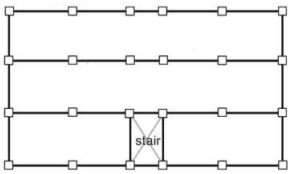


Wall structures

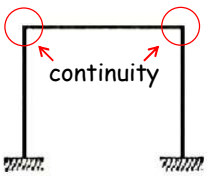


Dual structures

Inverted pendulum



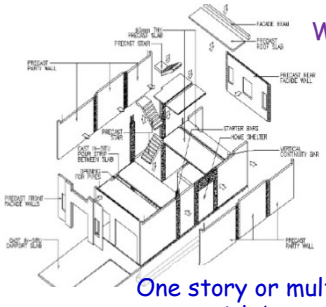
Torsionally flexible system



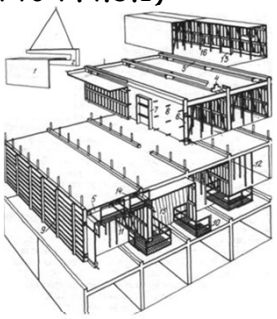
One storey inverted pendulum

Structural types…

7.4.5 For precast structures (in addition to 7.4.3.1)

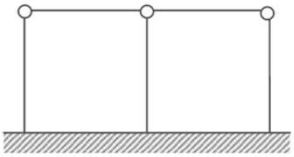


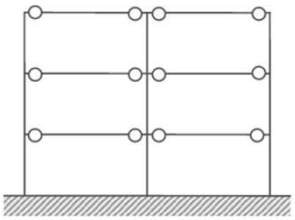
Wall panel structures



Cell structures

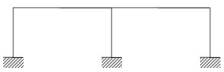
One story or multi stories frames with beams with weak joints

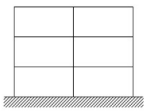




Structural types…

Precast frame structures:





Cast in situ connections (wet):

- Beam-to-column connections:
  1. Rules for concrete structures
- Base of the columns:
  1. Rules for concrete structures
  2. Overdesigned or emulative (mechanical connections)

Mechanical connections (dry):

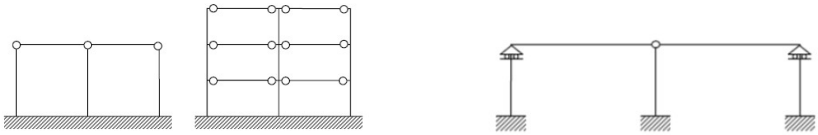
- Beam-to-column connections:
  1. Overdesigned, located away from critical zones, emulative
- Base of the columns:
  1. Rules for concrete structures
  2. Overdesigned or emulative (mechanical connections)

Structural types…

Frames with beams with weak joints

Mechanical connections:

- Beam-to-column connections:
  1. Overdesigned
- Base of the columns:
  1. Rules for concrete structures
  2. Overdesigned or emulative (mechanical connections)

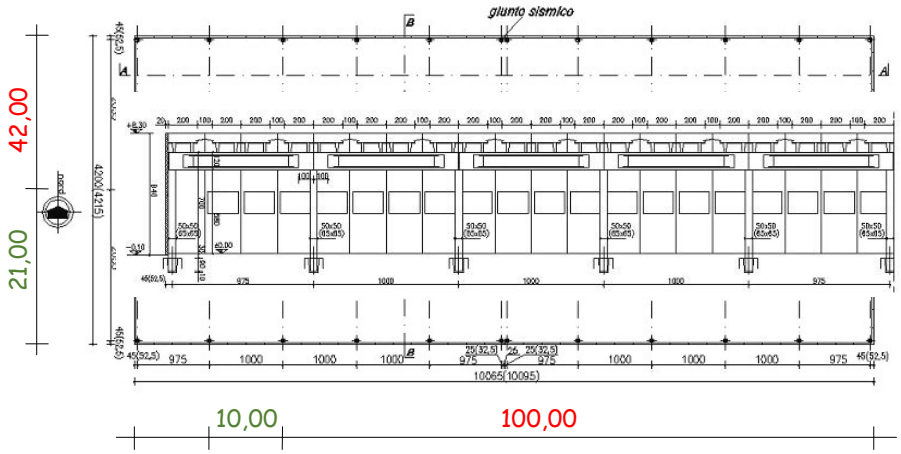


Behaviour factor

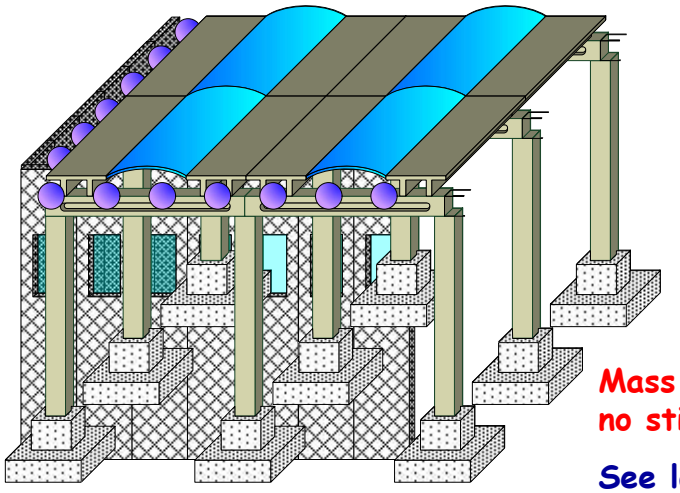
Structural Typology	CD"A"	CD"B"
Concrete structures (§ 7.4.3.2)		
Frame system, coupled wall system, dual syste,	4,5 α_u/α_1	3,0 α_u/α_1
Uncoupled wall system	4,0 α_u/α_1	3,0
Torsionally flexible system	3,0	2,0
Inverted pendulum	2,0	1,5
One storey inverted pendulum	3,5	2,5
Precast structures (§ 7.4.5.1)		
Wall panel structures	4,0 α_u/α_1	3,0
Cell structures	3,0	2,0
One story or multi stories frames with beams with weak joints	3,5	2,5

Other numbers are allowed if properly justified.

Structural modelling



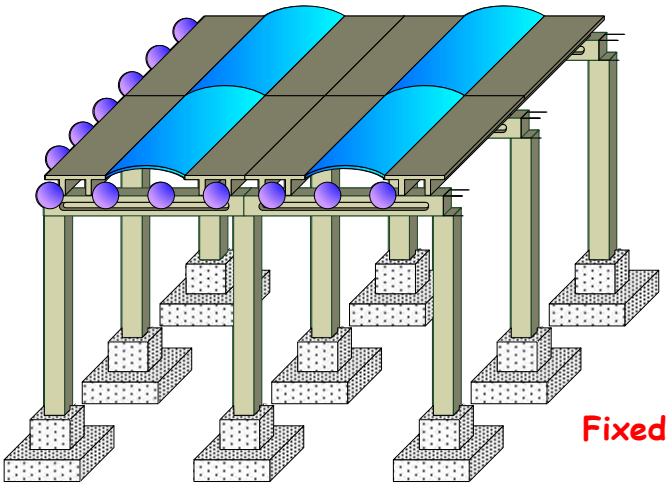
Structural modelling - panels



Mass only, no stiffness

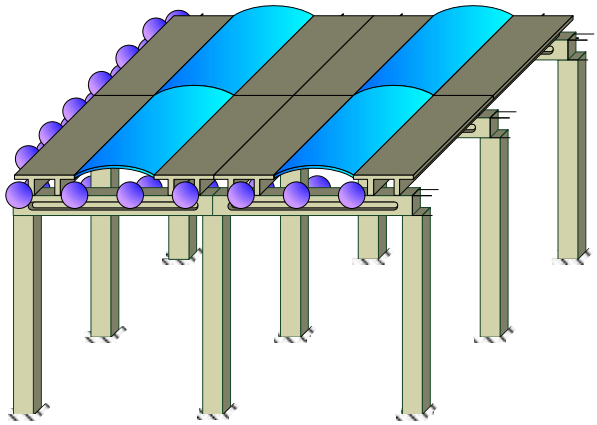
See later…

Structural modelling - foundations



Fixed point

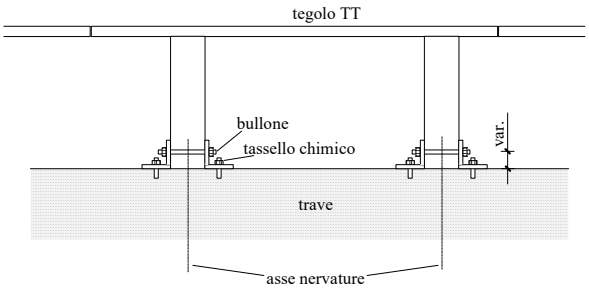
Structural modelling - structural elements



Beam elements (center of gravity)

Need of links to connect different beam elements

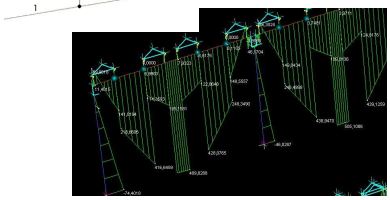
Structural modelling - Connections



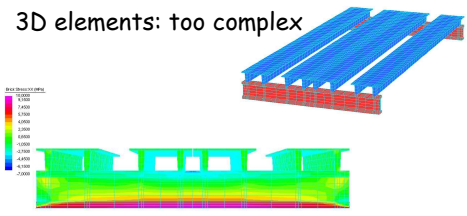
The roof to beam connection affects the deformability of the beam: how to model this effect?

Structural modelling - connections...

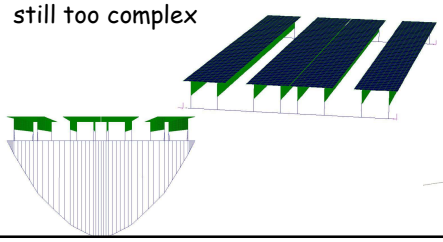
Beam elements + rigid links



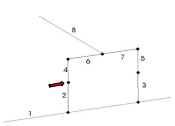
3D elements: too complex

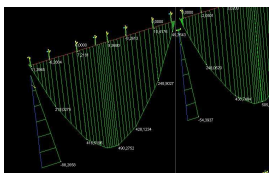


Shell elements + beam elemens: still too complex

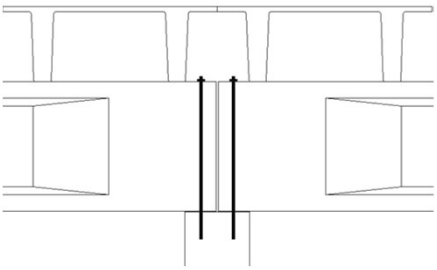


Max allowed simplification: beam elements + rigid links + deformable link.





Structural modelling – connections…

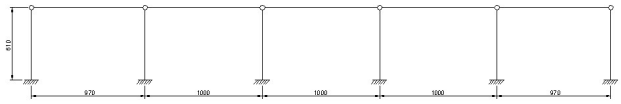


Hinge (only forces) in one direction and continuity (also moments) in the orthogonal direction.

Structural modelling – the end

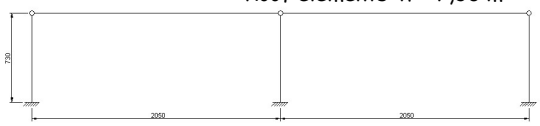
Longitudinal frames

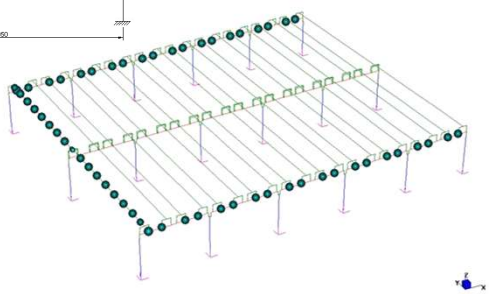
beam: h = 6,10 m



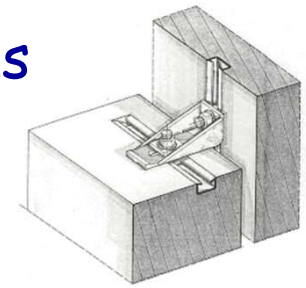
Transversal frames

Roof elements: h = 7,30 m

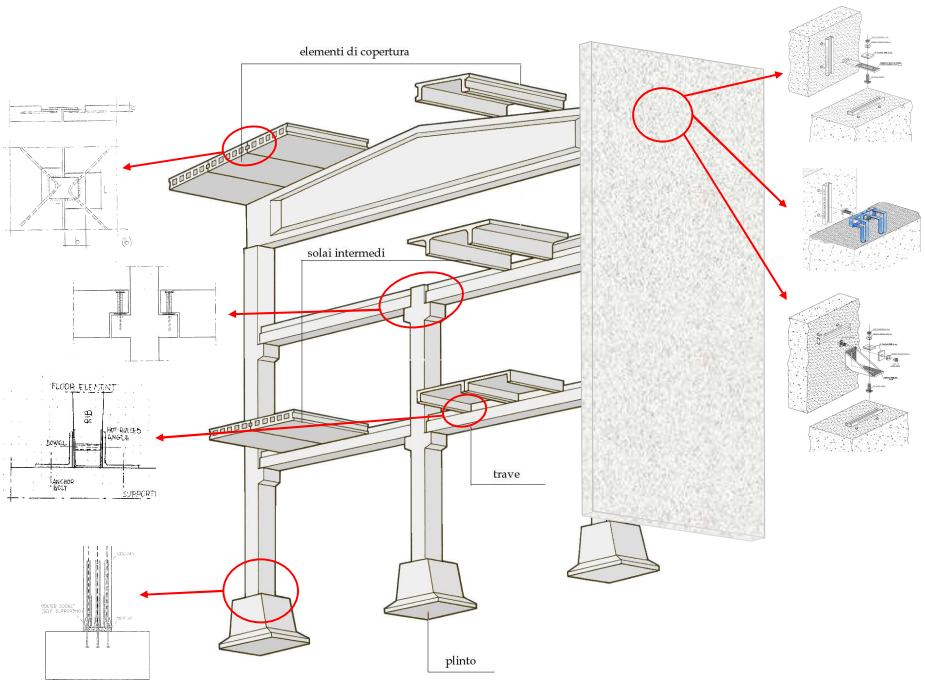


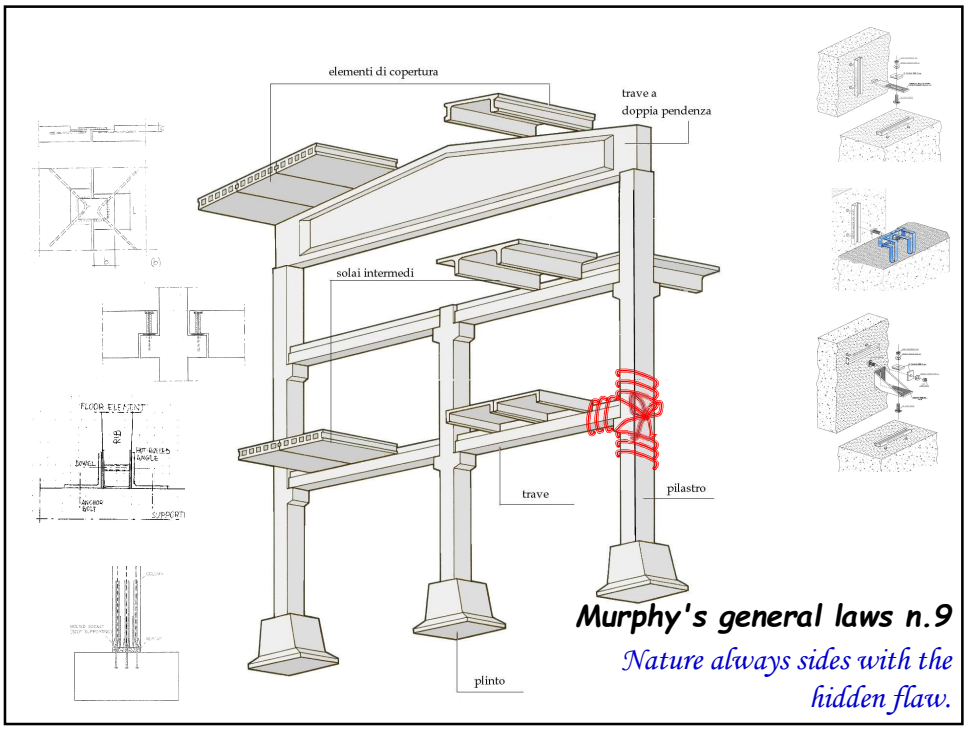


Connections



- Connections should be properly designed (forces, moments, deformations)
- Connections should be qualified according to specific indications
  - CE marking (EN, EOTA)
  - National procedures



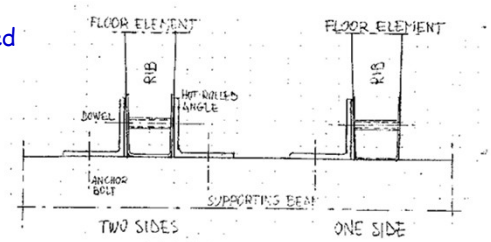


Murphy's general laws n.9

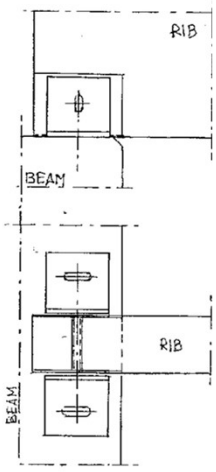
Nature always sides with the hidden flaw.

Connections…

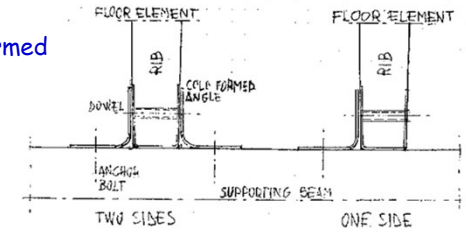
Hot rolled



Symmetric Asymmetric

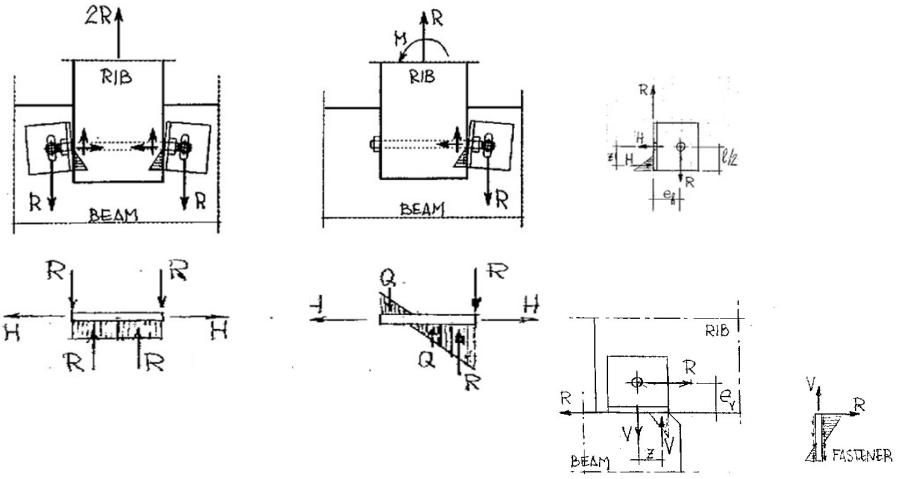


Cold formed

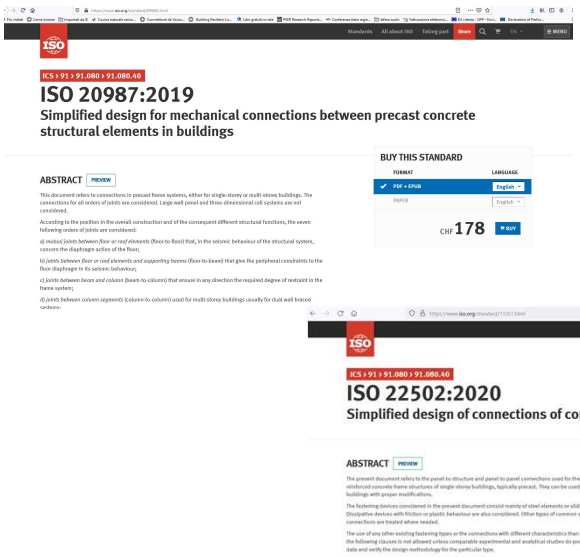


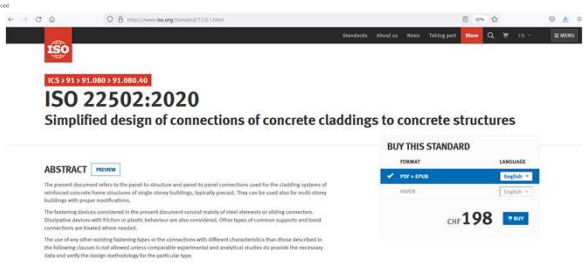
Connections…

Failure modes…

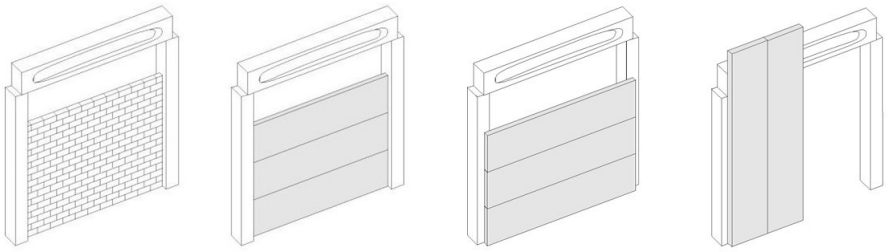


Technical support





Walls or panels



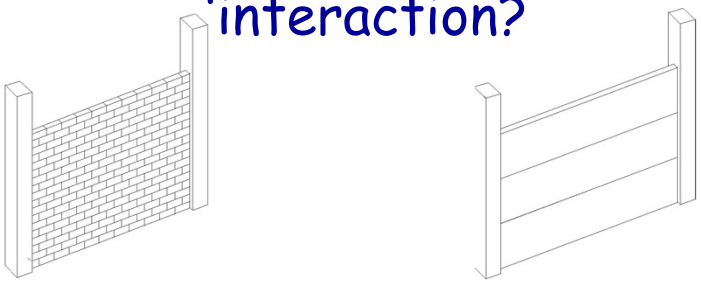
Different materials:
- Blocks
- Panels
- «Light»
- …

Different position:
- Inserted between columns
- Attached

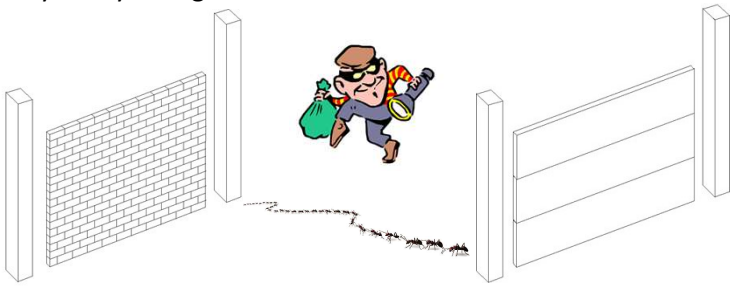
Different orientation:
- Horizontal
- Vertical

Different behaviour:
- Not interactive
- Just mass
- Mass plus stiffness

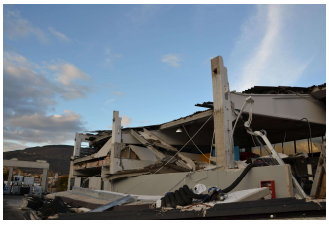
It is possible to reduce interaction?



Are they always integrated?



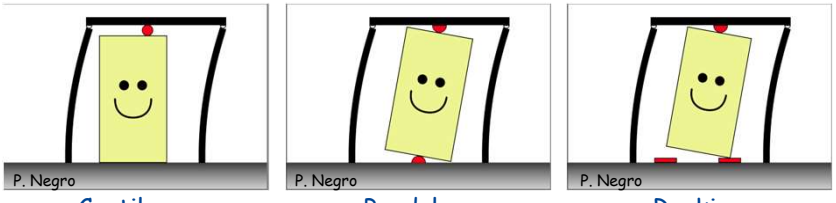
Improved fastening systems of cladding wall panels of precast buildings in seismic zones



Typology 1

- *ISOSTATIC SYSTEM*: No interaction between earthquake resistance structure and panels
- New connections able to allow relative movements between panels and structure
- Old design approach for the structure
- Pay attention to details

NOT INTERACTIVE

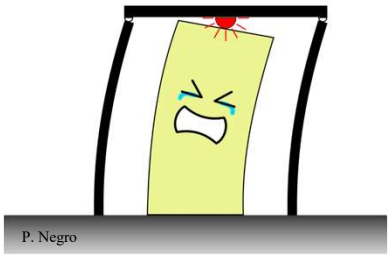


Cantilever Pendulum Rocking

Typology 2

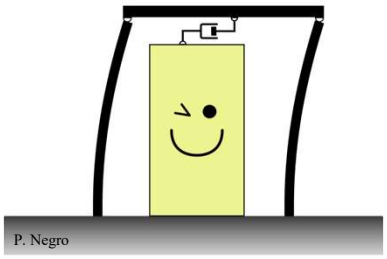
- *INTEGRATED SYSTEM*: Panels strongly connectes to the structure
- New connections able to transmit high forces
- New design approach for the whole structure and for panels

INTERACTING



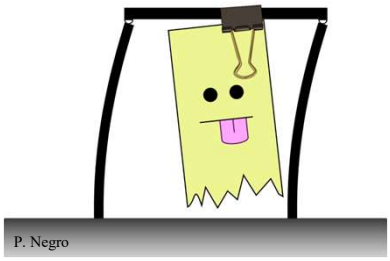
Typology 3

- *DISSIPATIVE SYSTEM*: Panels connected by means dissipative connections; combined earthquake resistance system
- New connections able to dissipate energy
- New design approach for the whole system

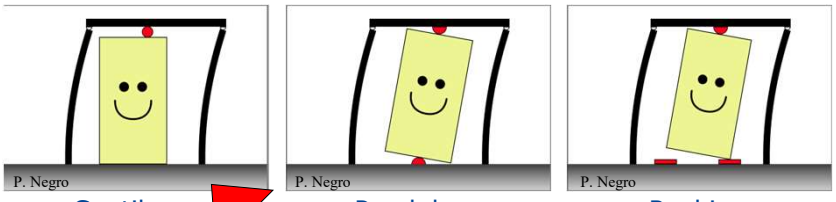


Typology 4

- *BACKUP SYSTEM*: for existing structures. Additional connections that avoid the collapse of the panel
- New connections



Isostaic systems

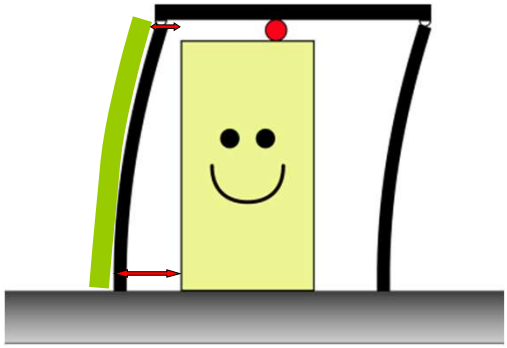


Cantilever Pendulum Rocking

Common problems

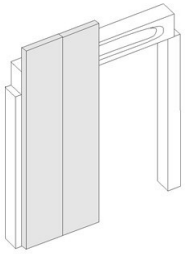
Corner interaction (both horizontal and vertical panels)

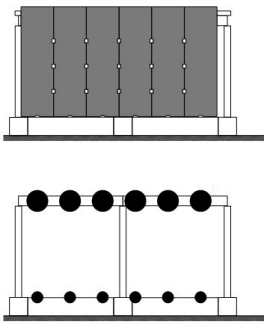
- The directions of the earthquakes usually do not coincide with main directions of the structures
- The behaviour of the structure in the two directions is not independent
- The structure is a 3D entity



Common problems …

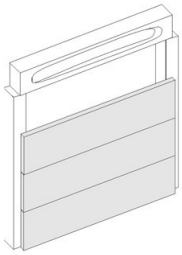
- **Vertical panels**:
  - Only the upper X% of the panel mass contributes to the seismic behaviour of the structure and is applied to beams
  - Also the roof elements mass is applied to beams
  - No additional masses are applied to columns
  - In the transversal direction the panel mass is applied to roof elements

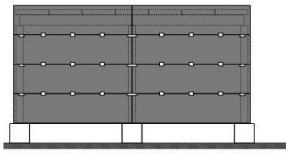


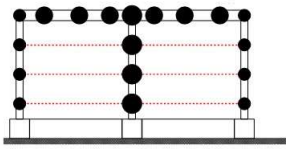


Common problems …

- **Horizontal panels** (main direction):
  - The panel mass is applied to columns
  - The central columns are charged by a double mass (panels in each side)
  - The roof mass is applied to beams



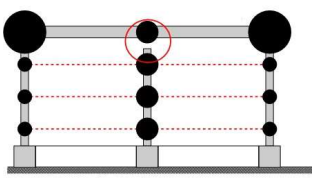




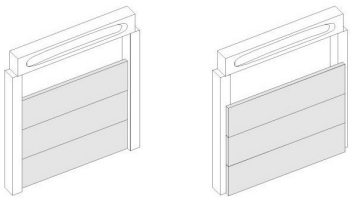
Common problems …

- **Horizontal panels** (transversal direction):
  - The panel mass is applied to columns
  - Pay attention to non-loaded columns
  - Non-loaded columns are connected to the structures through panels
  - The mass acting on non-loaded columns is different from that of other columns (non vertical load from roof)
  - The dynamic behaviour of non-loaded columns is different from the rest of the structure
  - Problems with the connections of the upper panels

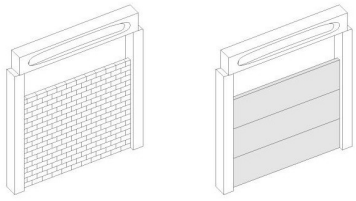
$$T = 2\pi\sqrt{\frac{m}{k}}$$



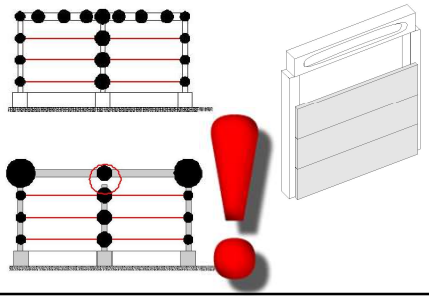
Common problems …

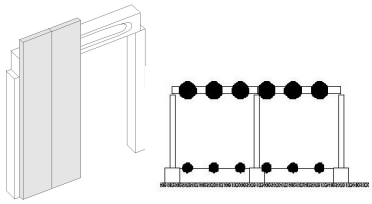


Integrated or not?



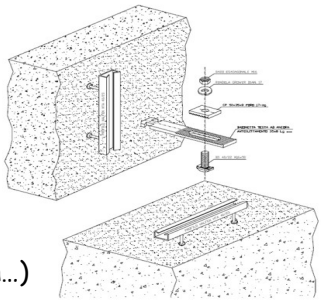
Only mass or mass&stiffness?





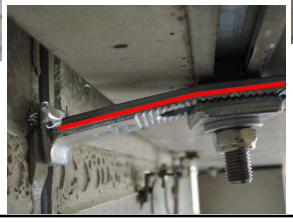
Sliding connections

- Do they slide in reality?
- If not, why?
- Tollerances, dust, waste, …
- Low friction coating does not work
- Unexpected friction



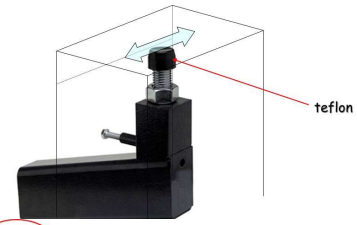
- What about 3D effects?
  (tests are usually performed in one direction…)
- Connection ≠ whole structure

Sliding connections…

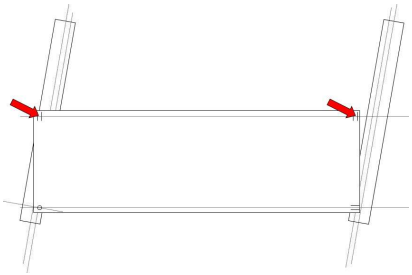


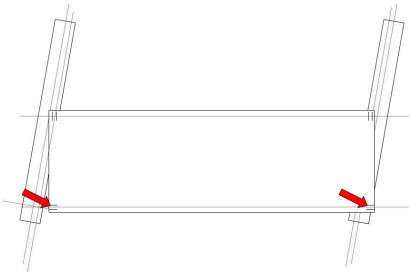
Sliding connections…

- Supporting system for panels



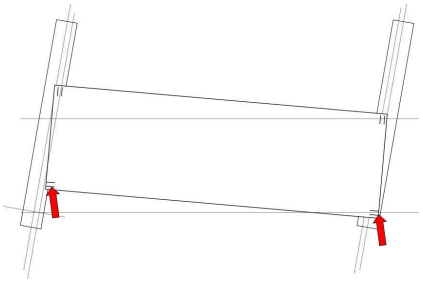
Geometry of the system…



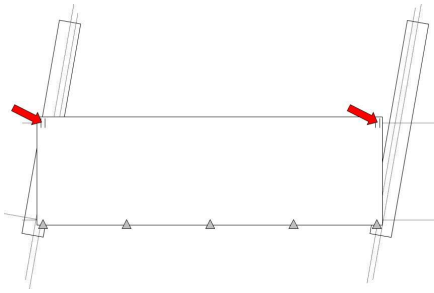


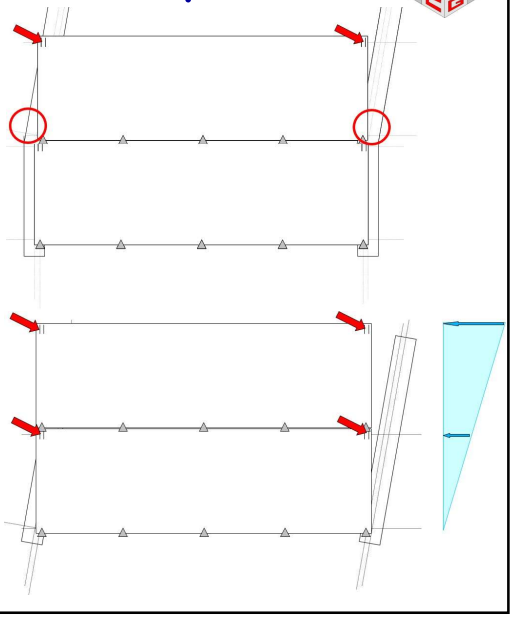
Behaviour of the base panel:

Potential problems with connections in the upper or lower part of the panel



Geometry of the system…





Is It really isostatic?

Real position of the plastic hinge.

Forces acting in connections.

Geometry of the system…

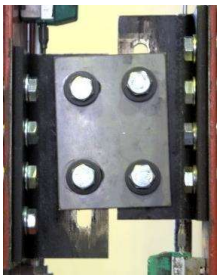
Scheme of the connection

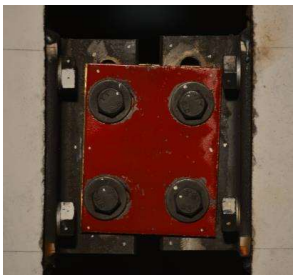
Horizontal panels:

- How are they connected to the structure?
- Is this the best scheme?
- Is it possible to use an orthodox approach?
- But… what is an orthodox approach (*cit. prof. Toniolo*)?
  In other words, what is the best way to hang a painting?

Dissipative systems

- Dissipative systems are subjected to CE marking according to EN 15129 "Anti-seismic devices"
- Dissipative systems must be rigidly connected to the structure: gaps, relative movements and so on modify the global behaviour of the system and have to be included in the certification of the system
- Tollerances in execution do not help …





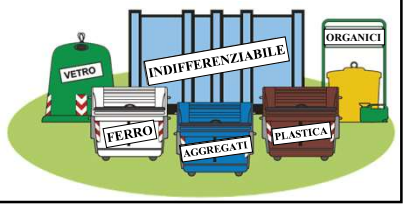
Welding

- Quality of welding is essential
- Welding must be done by certified operator

Do not forget sustainability

Design for disassembly

Separate collection for recycling



End… tomorrow?

Design

- Revision of Eurocodes
  (Italian mirror group EC8, WG5 – Concrete)
- Revision of NTC

Certification

- EADs for connections in precast structures

CE ETA

ASSOBETON

Thank you!!!

Antonella Colombo

4 February 2022