Conceptual seismic design of new buildings

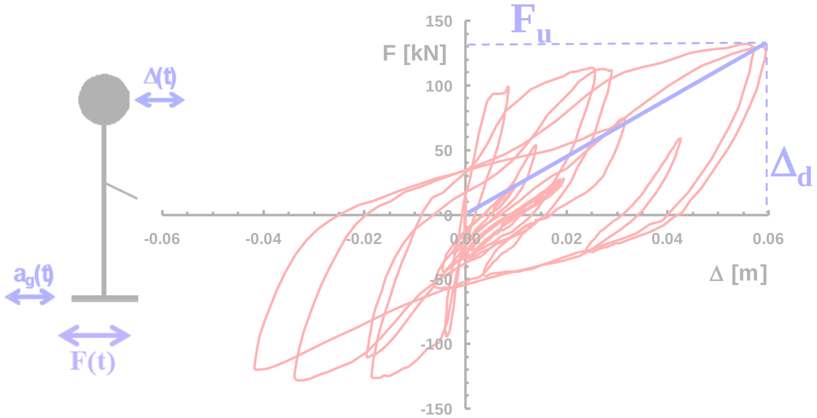
Seismic engineering

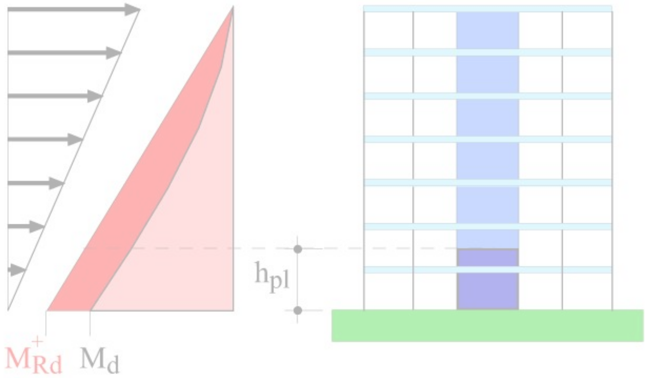
Dr. Igor Tomić

Course objectives

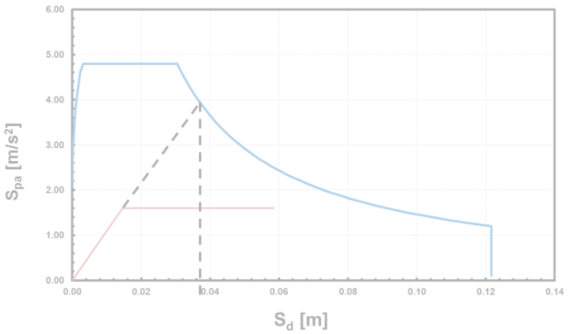
Know typical failure modes of structures during earthquakes.

Know how to estimate the peak forces and displacements of structures subjected to earthquakes.





Know how to design new buildings with reinforced concrete walls.



Know the basic elements of a displacement-based evaluation of existing structures.

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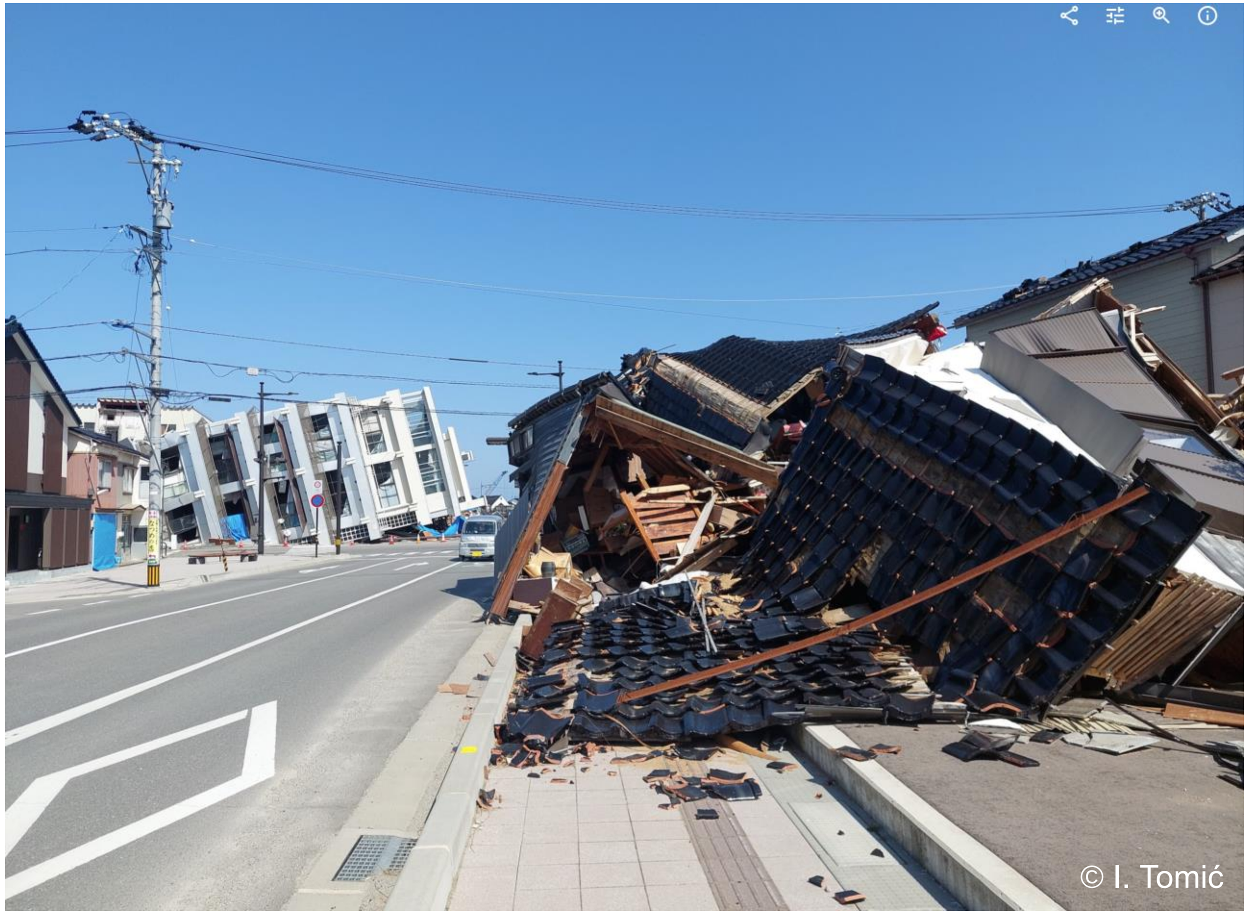
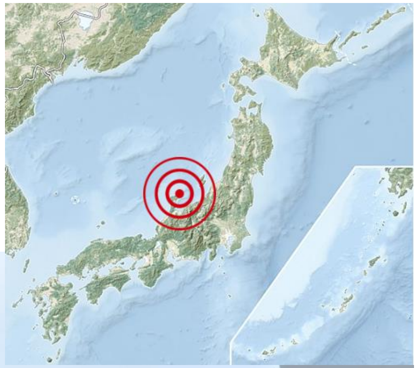
Course objectives

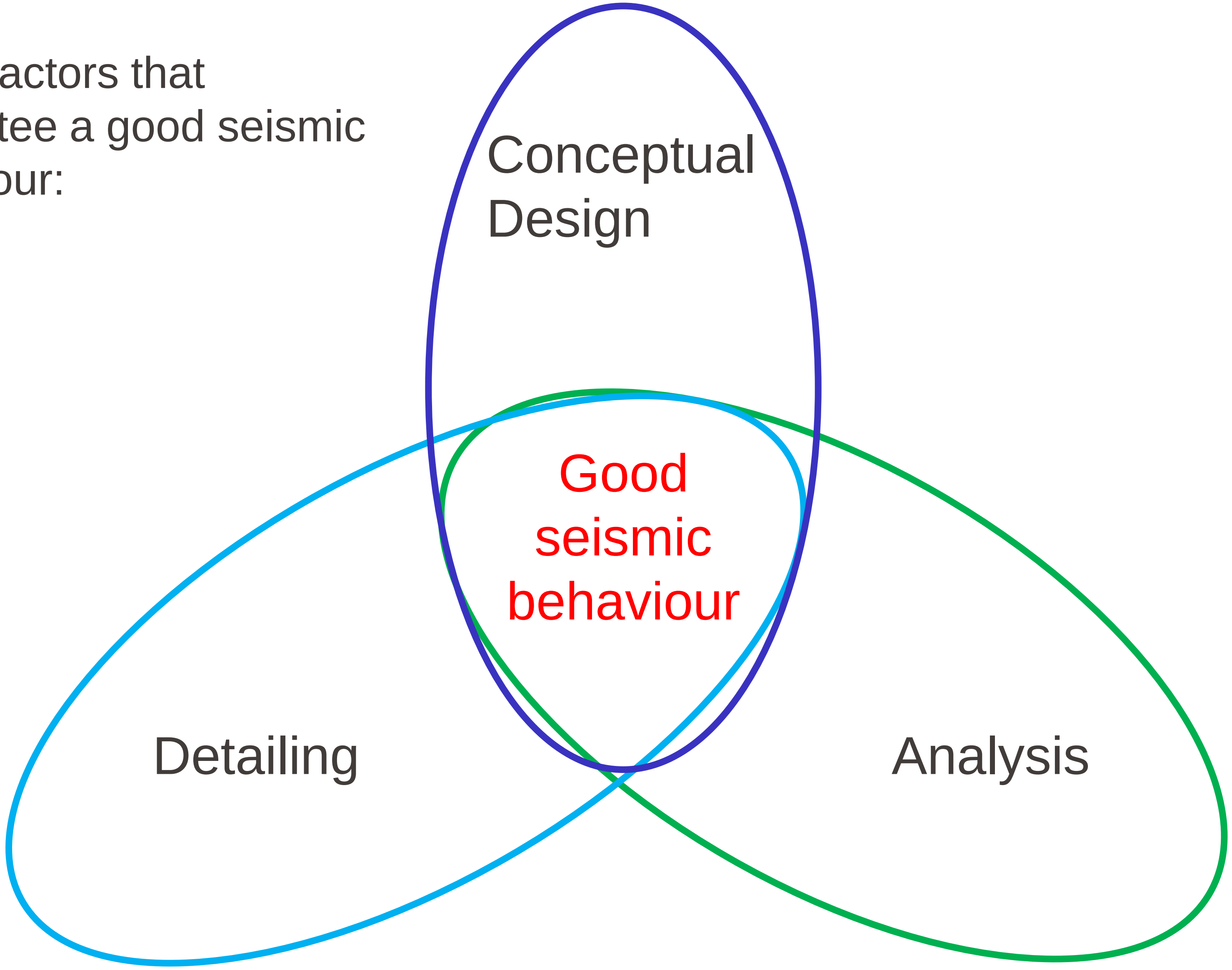




Conceptual seismic design of new buildings

Dr. Igor Tomić

Three factors that guarantee a good seismic behaviour:



Conceptual seismic design

Reference:

Bachmann, H. (2003) « Seismic conceptual design of buildings – basic principles for engineers, architects, building owners and authorities», Federal Office for Water and Geology, Bern, Switzerland.

Conceptual seismic design

Principal idea of the conceptual seismic design guidelines that are presented in the following:

- The seismic behaviour of structures is very complex (cyclic, inelastic dynamic behaviour).
- Aim for a simple structural system (Regularity, symmetry and continuity of the structural elements in plan and elevation)

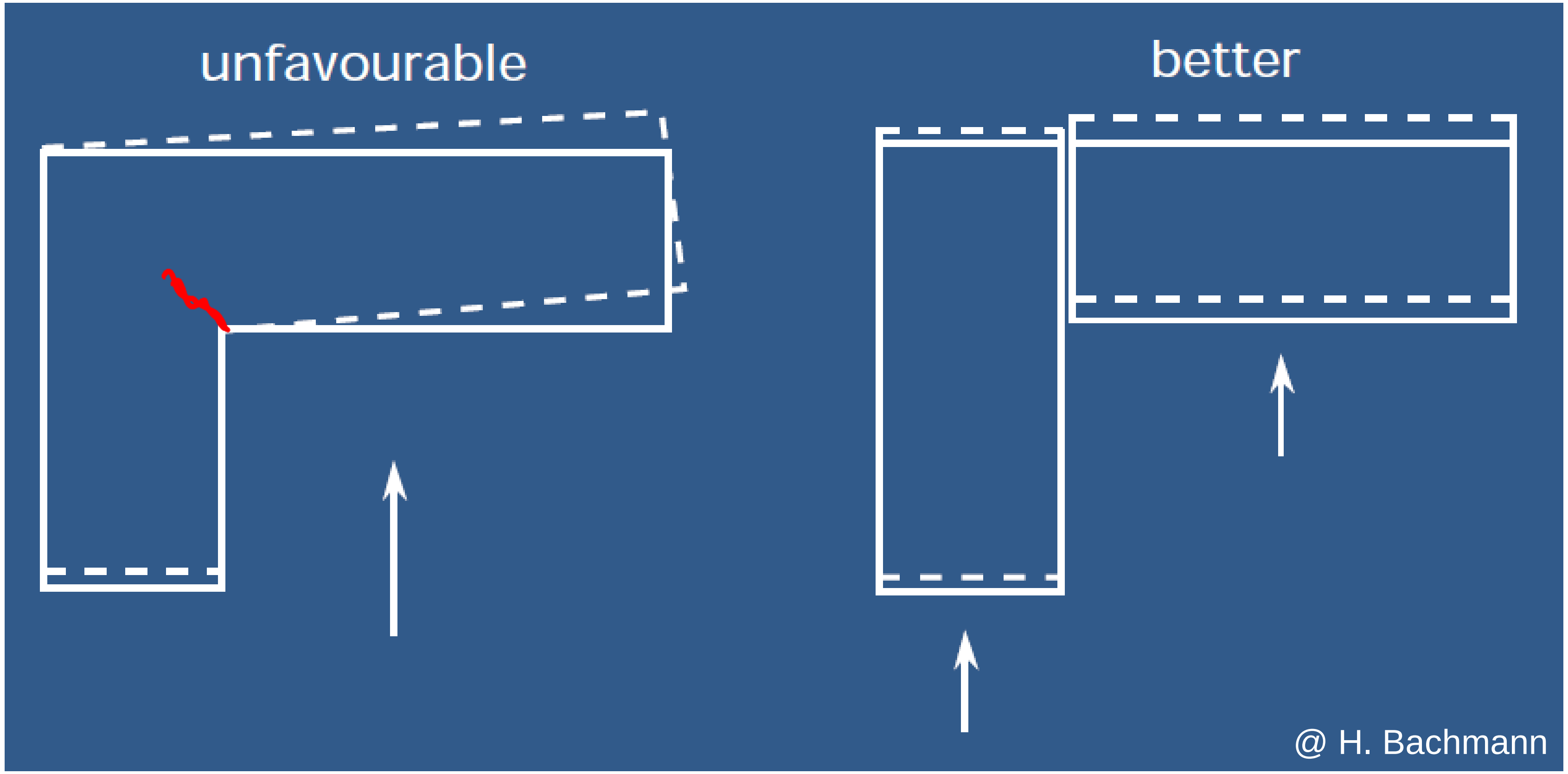
  → Easier to understand, predict and build

Following slides:

- Rules for conceptual design of buildings

Conceptual seismic design

Favour compact plan configurations!

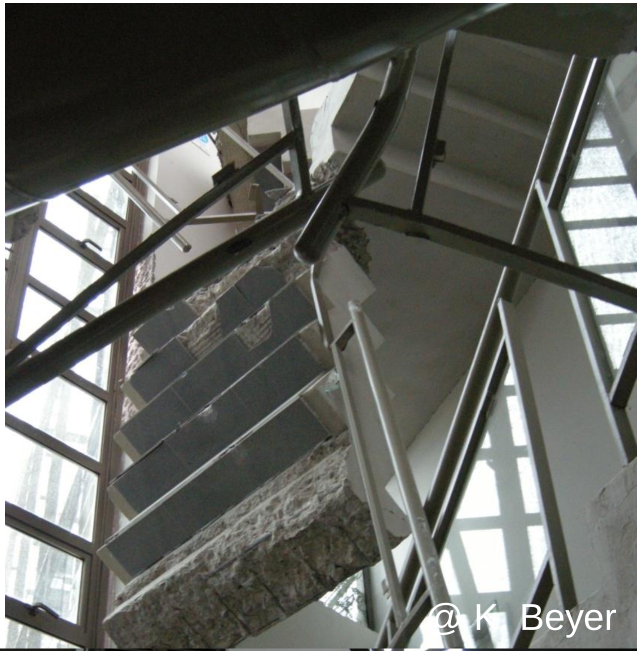


Conceptual seismic design

Careful when coupling building parts with a very different horizontal stiffness!

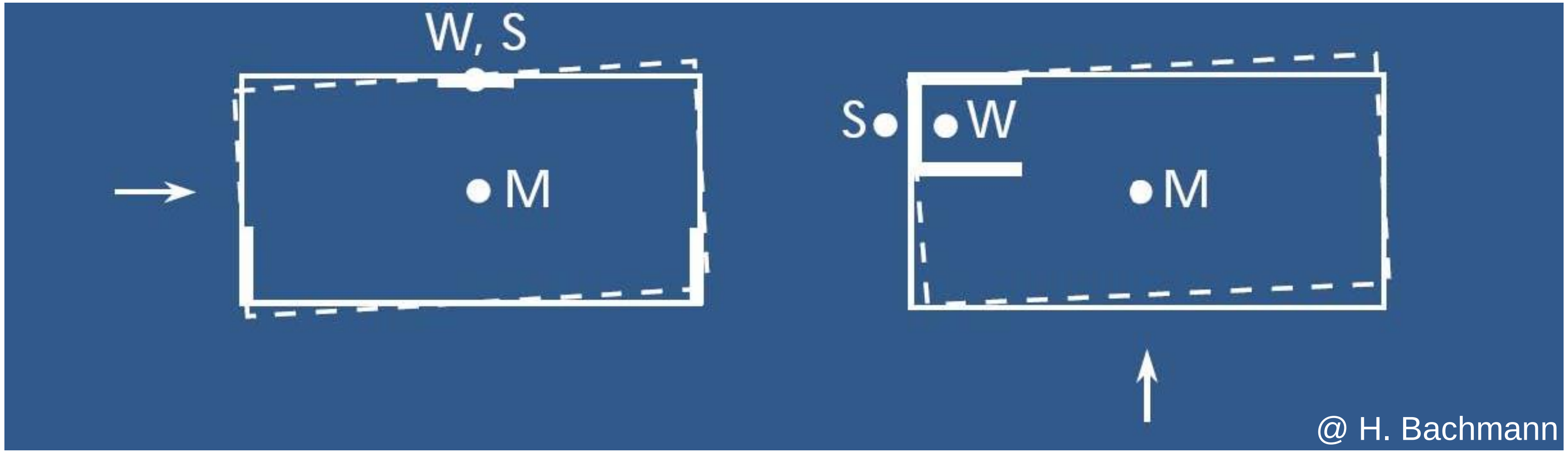
Conceptual seismic design

Careful when coupling building parts with a very different horizontal stiffness!



Conceptual seismic design

Avoid asymmetrical horizontal bracing!



Large rotations of the building if there are large eccentricities between M & S (elastic response) or M & W & S (inelastic response)

$$x_s = \frac{\sum k_{y_i} x_i}{\sum k_{y_i}}$$

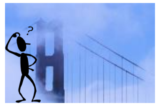
M = Centre of mass (points where resultant of inertia forces acts)

S = Centre of stiffness

W = Centre of strength

$$y_s = \frac{\sum k_{x_i} y_i}{\sum k_{x_i}}$$

One question…



This image shows a building with an eccentric core. Large rotations are to be expected during an earthquake. Is this of concern?

A. Yes, because the columns or slab-column connections might fail.

B. Yes, because non-structural elements not yet shown on the photo might fail.

C. No, because the columns are so flexible that they can easily accommodate the larger displacement demand.

D. No, because the displacement demand on the concrete core, i.e., the element that provides horizontal stiffness and strength, is not significantly increased.

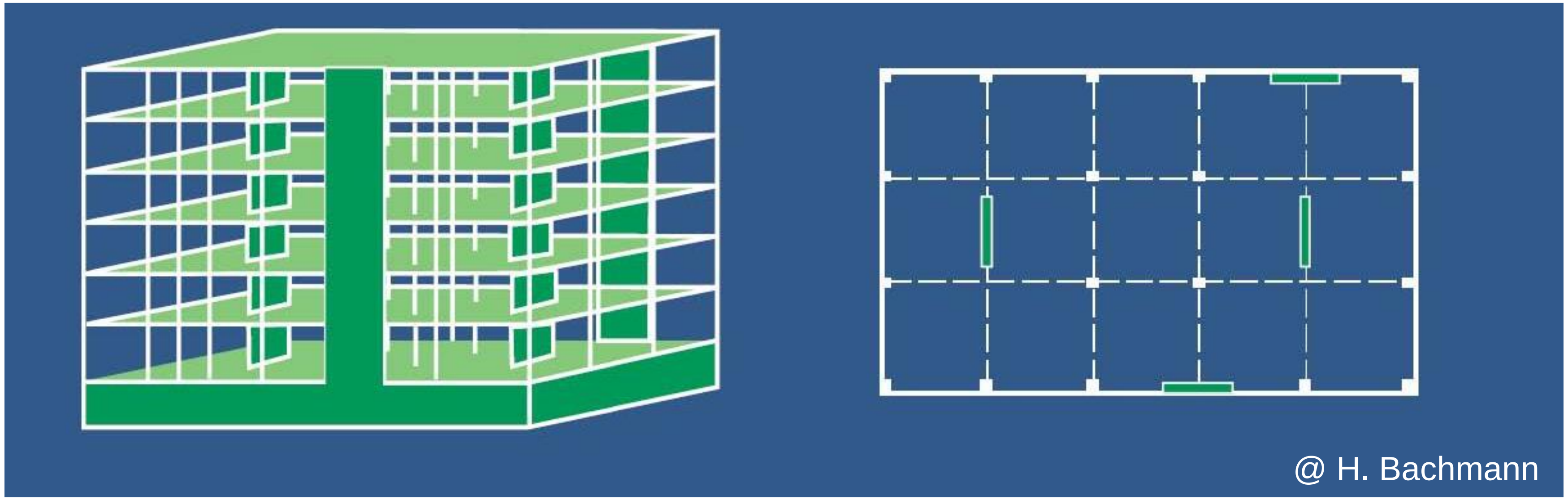
E. Yes, because diaphragm forces become very large.

Conceptual seismic design

Irregularity in plan (and elevation)
Weak faces of the building are heavily damaged

Conceptual seismic design

RC buildings with slender structural walls



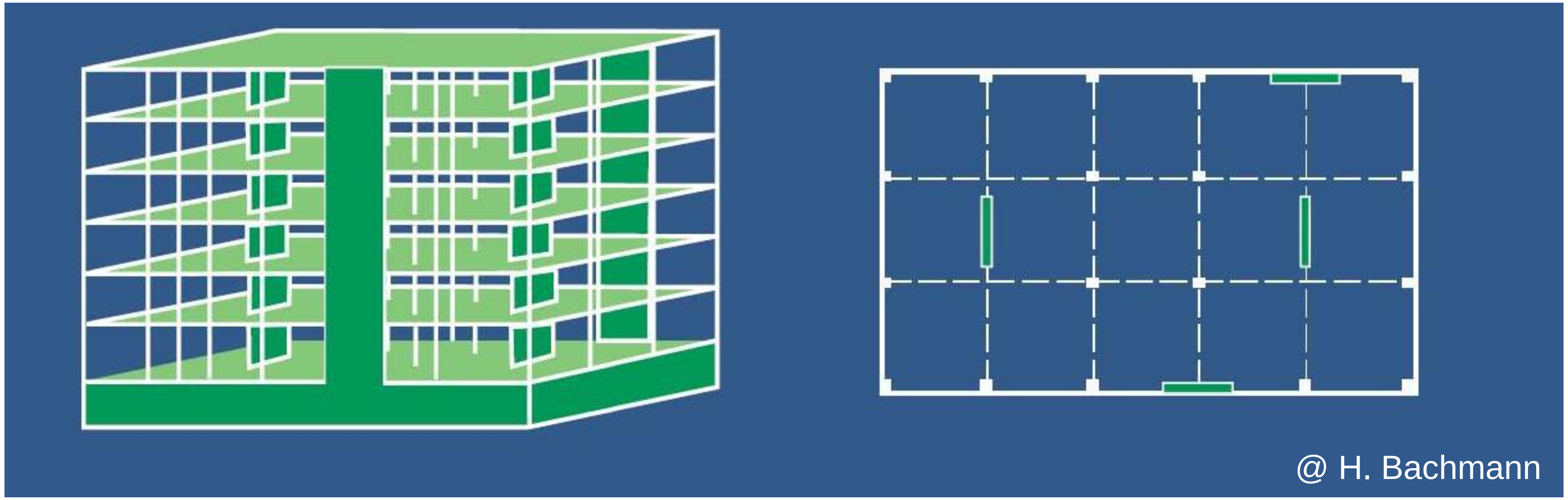
At least two slender walls in each horizontal direction ensure:

- High structural safety if walls are capacity designed
- High torsional stiffness if walls are close to the perimenter
- A good control of interstorey drifts (and hence little damage to non-structrual elements that are drift sensitive)

→ Robust behaviour

Conceptual seismic design

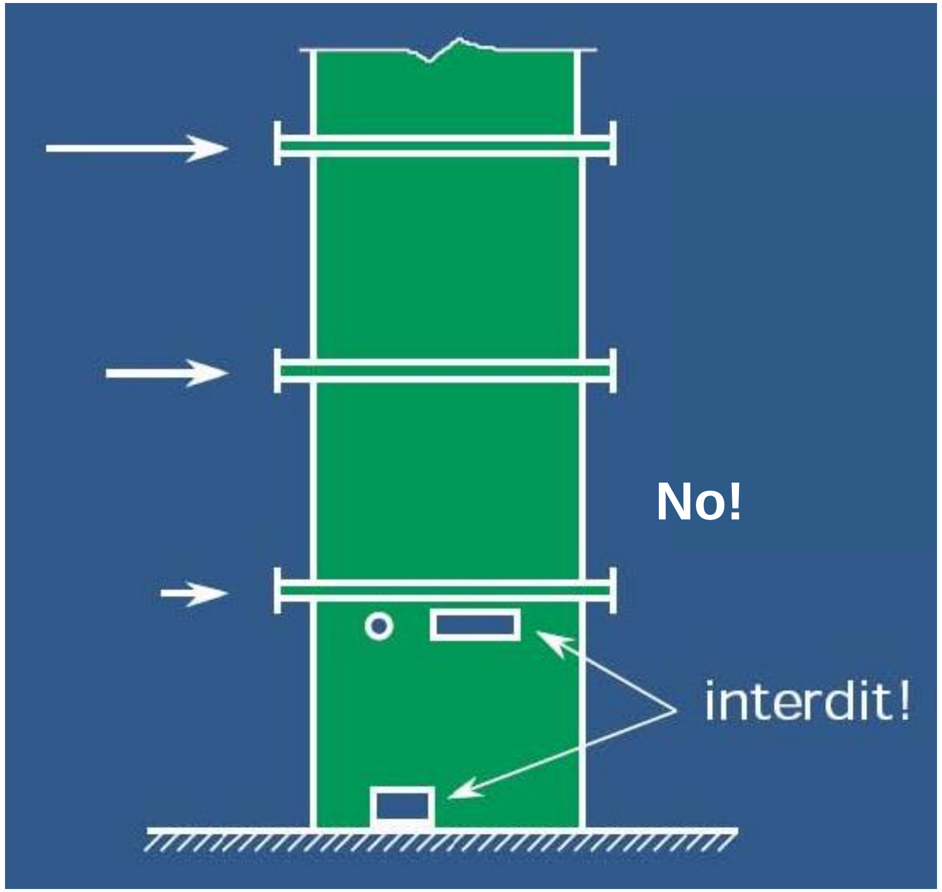
Offer alternative load paths

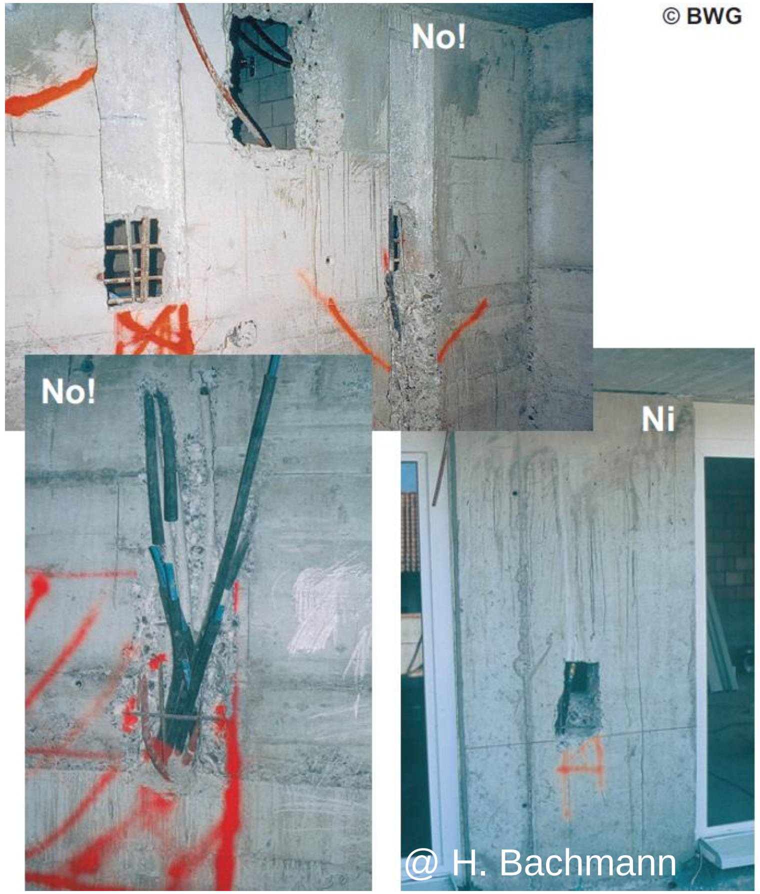


- Build hyperstatic structures: If one element fails, the loads can be redistributed.
- Necessary for the redistribution of loads in buildings: Diaphragms that are stiff.

Conceptual seismic design

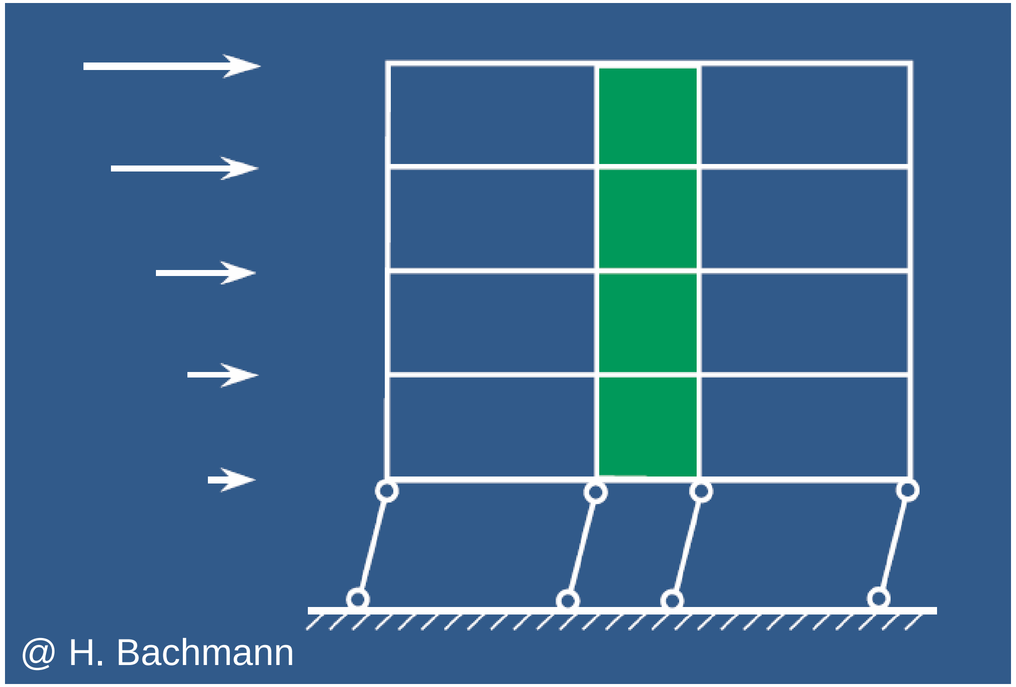
No openings in the plastic zone!





© BWG

Avoid soft storey mechanisms!



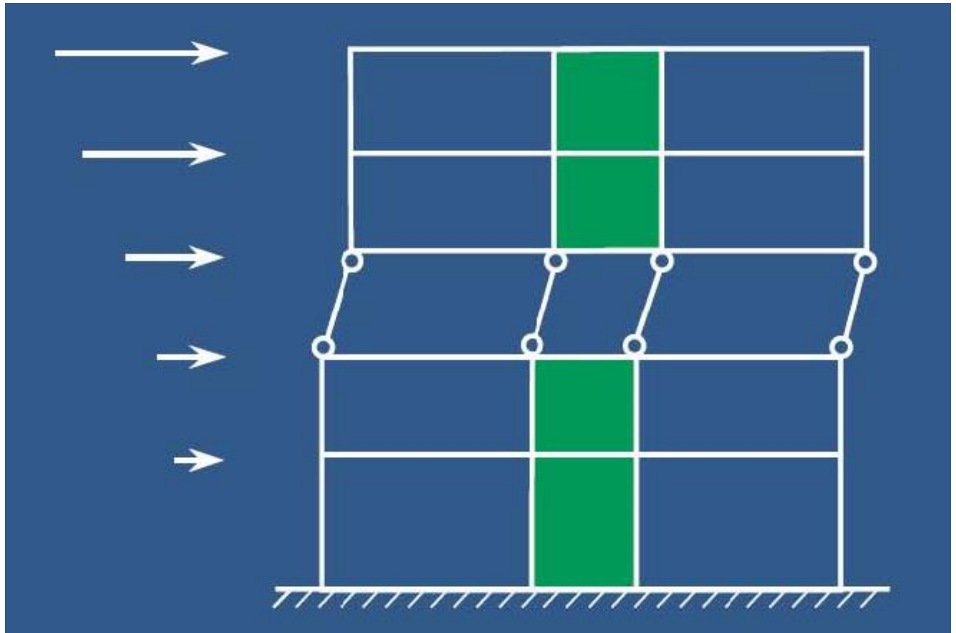
- One of the most frequent causes for the collapse of buildings
- Architectural reason: Open space at ground floor for shops or parking lots

Video

@ Enea Beltrami, Mattia Benagli

Conceptual seismic design

Avoid soft storeys!



@ H. Bachmann

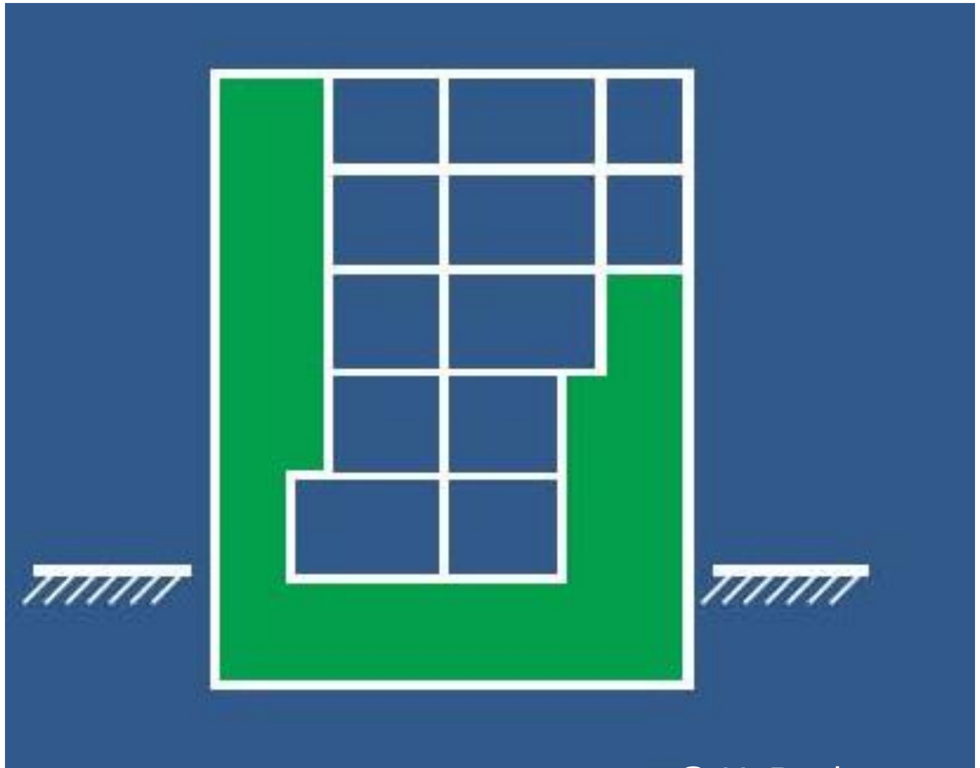
O'Higgings Buiding, Concepción

Video

@ Enea Beltrami, Mattia Benagli

Conceptual seismic design

Vertical discontinuities in stiffness and strength cause problems!

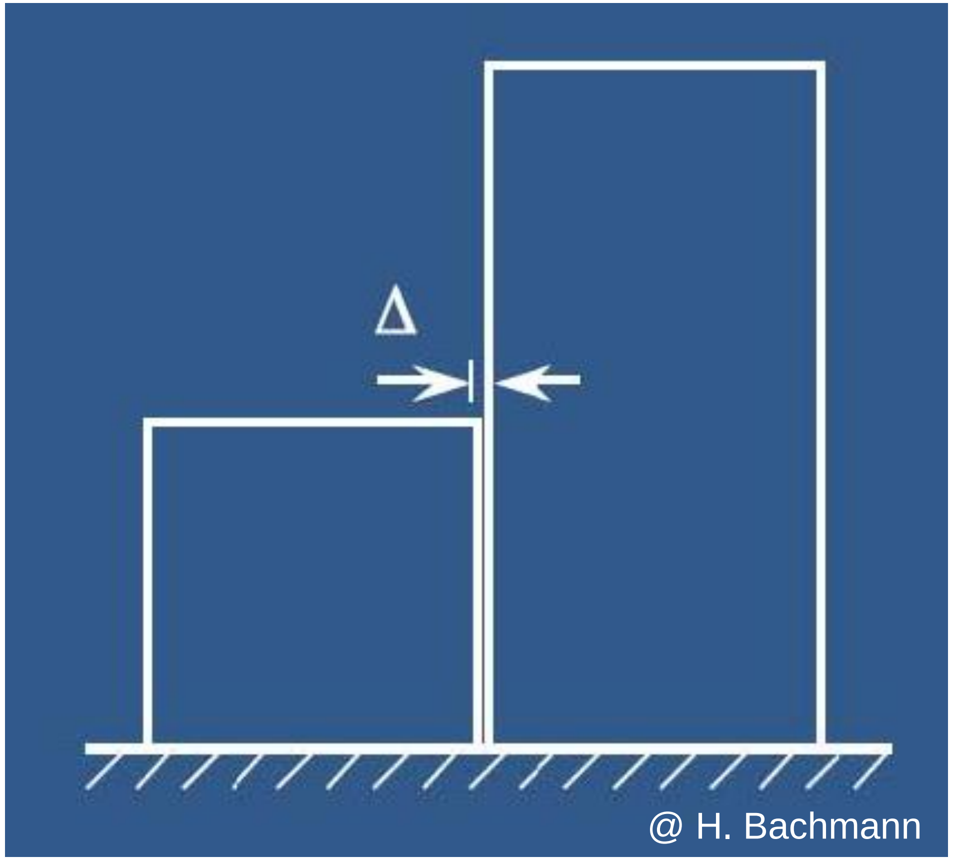


@ H. Bachmann

O'Higgings Buiding, Concepción @ K. Beyer

Conceptual seismic design

Separate adjacent buildings by joints to avoid pounding or design buildings in such a way that damage due to pounding does not compromise the structural safety!



Conceptual seismic design


@ P. Lestuzzi


@ P. Lestuzzi

If slabs of adjacent buildings are at the same height, the damage due to pounding is often limited.

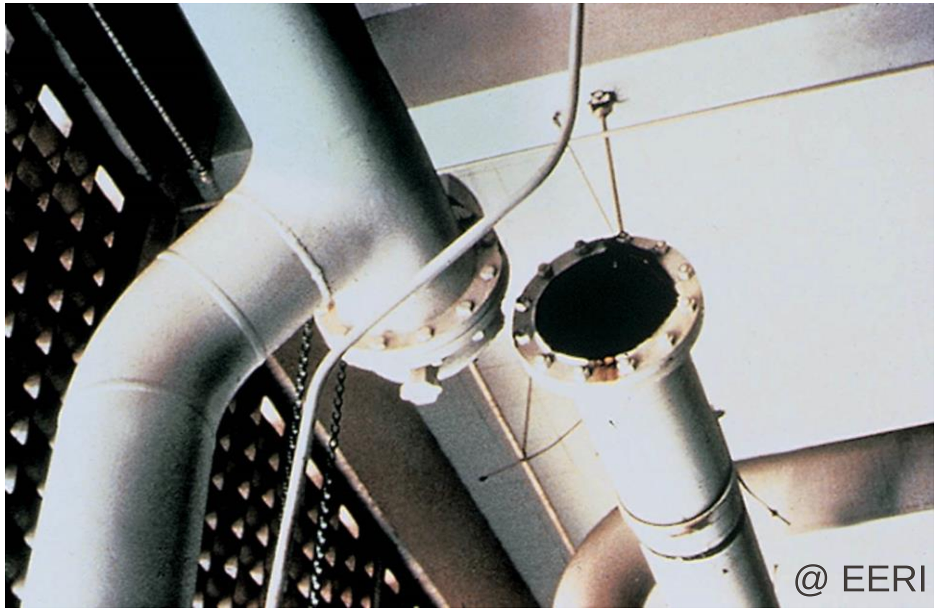
Non-structural elements

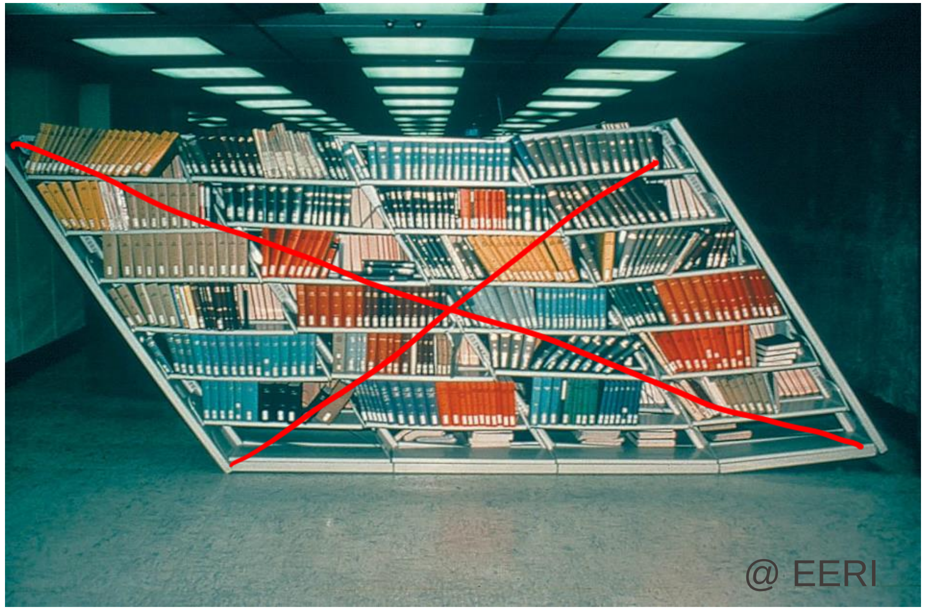
Damage to nonstructural elements:

- Free standing parapet
- Facade elements
- Suspended ceiling

Non-structural elements

Non-structural elements





Non-structural elements

Non-structural elements and building content

- Two classes of non-structural elements:
  - Class 1: Non-structural elements that are mainly damaged due to accelerations of the structure (floor accelerations)
  - Class 2: Non-structural elements that are mainly damaged due to deformations of the structure (inter-storey drift)

- Possible consequences of damaged to non-structural components:
  - Damage to the structure (applies in particular to masonry infills)
  - Danger to people (falling pieces)
  - Emission of dangerous substances (damage to piping, storage tanks)
  - Fire
  - Indirect effects (ex.: blocked emergency exits)
  - Costs

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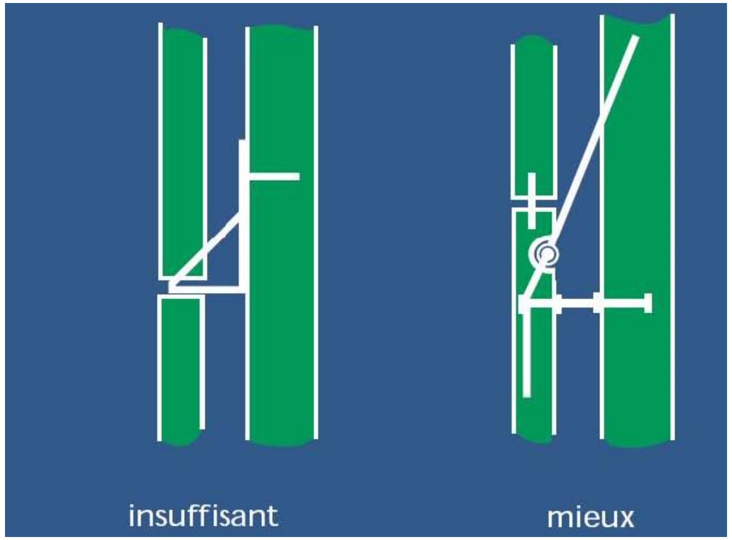
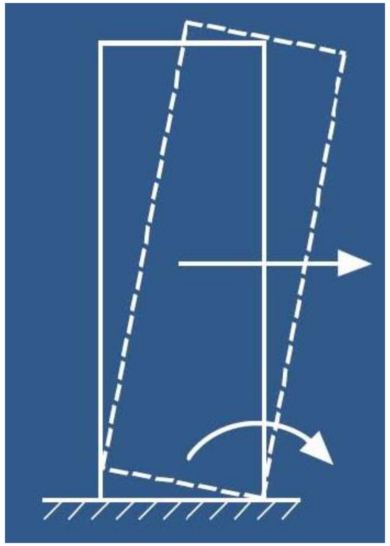
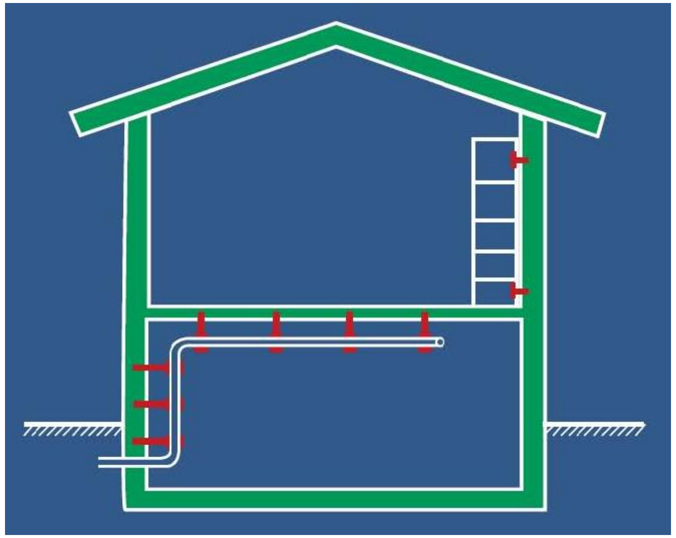
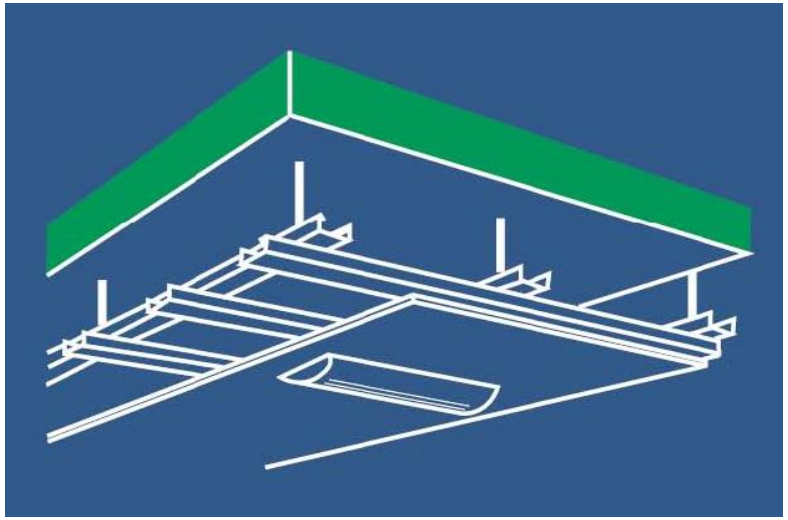
Fire

Non-structural elements







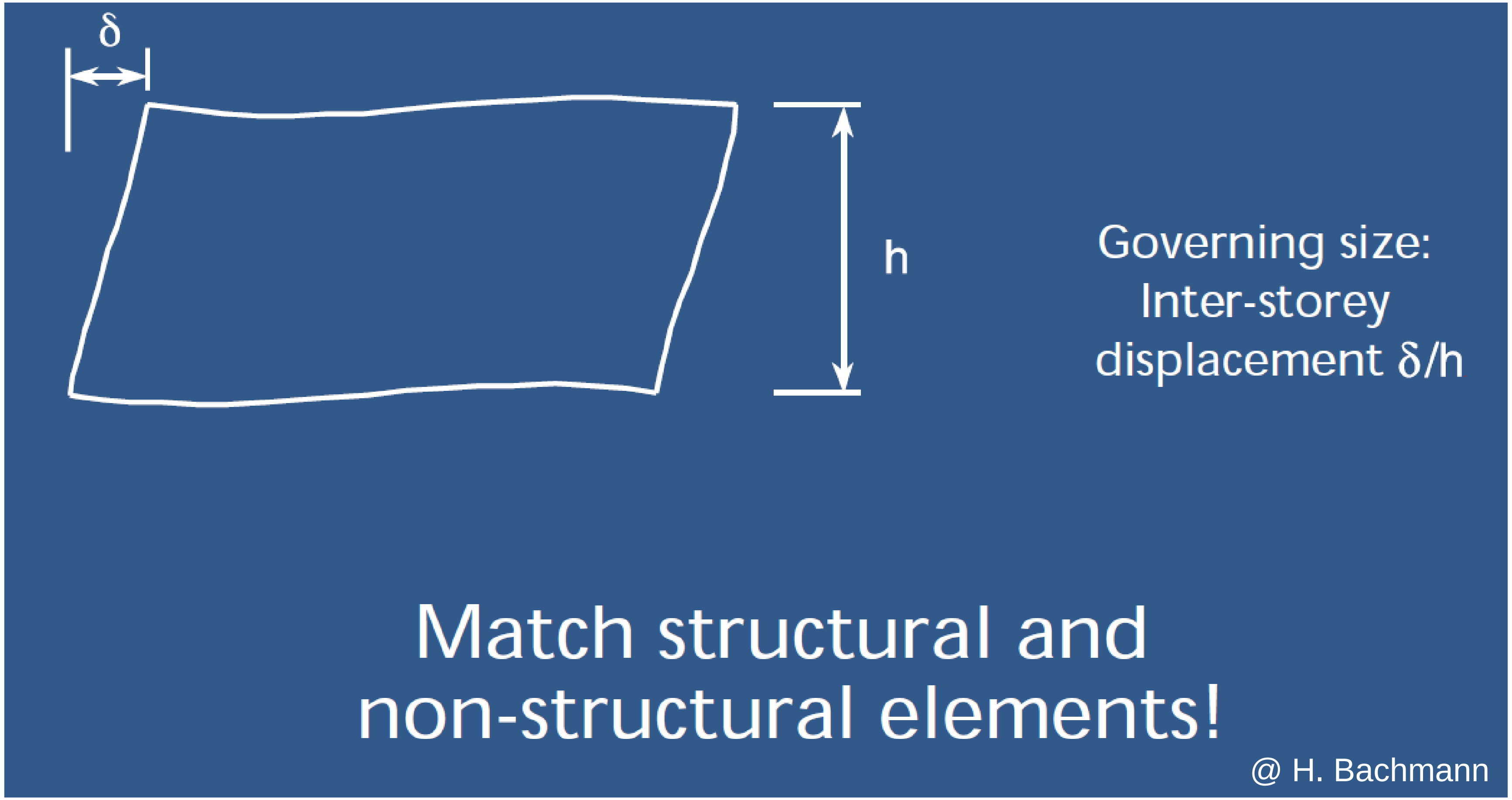


@ H. Bachmann

Avoid damage to acceleration-sensitive non-structural elements:

- Anchor facade elements, piping, furniture, suspended ceilings
- Avoid free standing masonry walls and parapets

Non-structural elements



Damage due to drift-sensitive non-structural elements:

- Infill walls, lift shafts, pipes that pass over several storeys, …

Conceptual design

Summary of conceptual design guidelines:

- Aim for a simple structural system (Regularity, symmetry and continuity of the structural elements in plan and elevation)

  → Easier to understand, predict and build

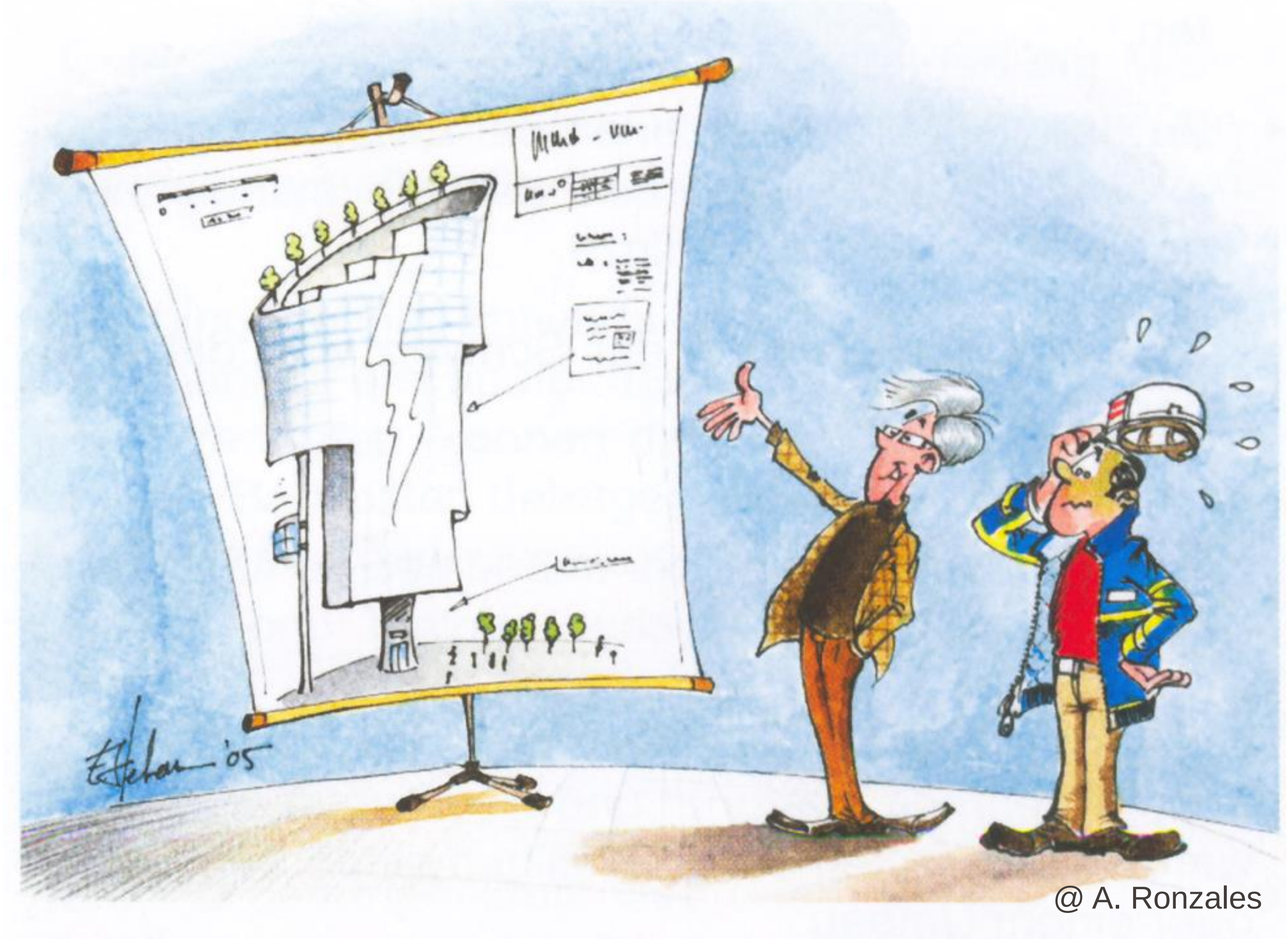
- Provide stiffness and strength in the two horizontal directions
- Provide torsional stiffness and strength
- Use hyperstatic systems (redundant systems)
- Design floors with in-plane stiffness and strength (important for the distribution of inertia forces)
- Detail the structural elements so that they have a ductile behaviour (=capacity to deform in the inelastic range)
- Provide an adequate foundation
- Consider also the non-structural elements

Aim for a robust behaviour!

Conceptual seismic design

→ Requires cooperation between architect and engineer

Avoid:



@ A. Ronzales

Conceptual seismic design

Structural systems for providing horizontal stiffness and strength

- Moment resisting frames
  - Reinforced concrete, steel, timber
- Structures with single or coupled walls
  - Reinforced concrete or reinforced masonry
- Dual wall-frame systems
  - Reinforced concrete frames coupled to reinforced concrete walls
- Trusses with centric or eccentric bracing
  - Steel

An alternative to classical structural systems:

- Base isolation

Moment resisting frames in RC

© U. Yazgan

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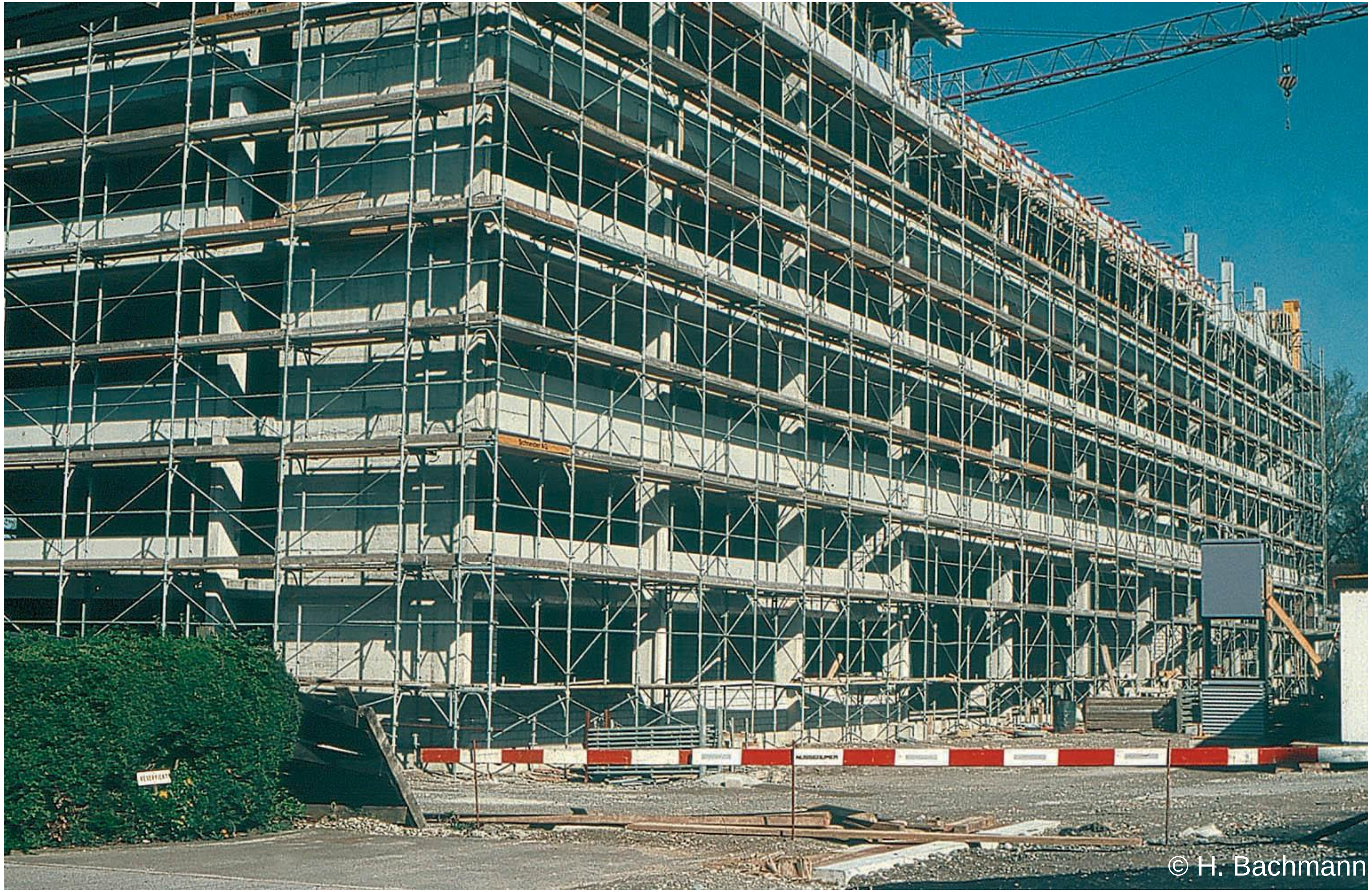
Building with RC walls



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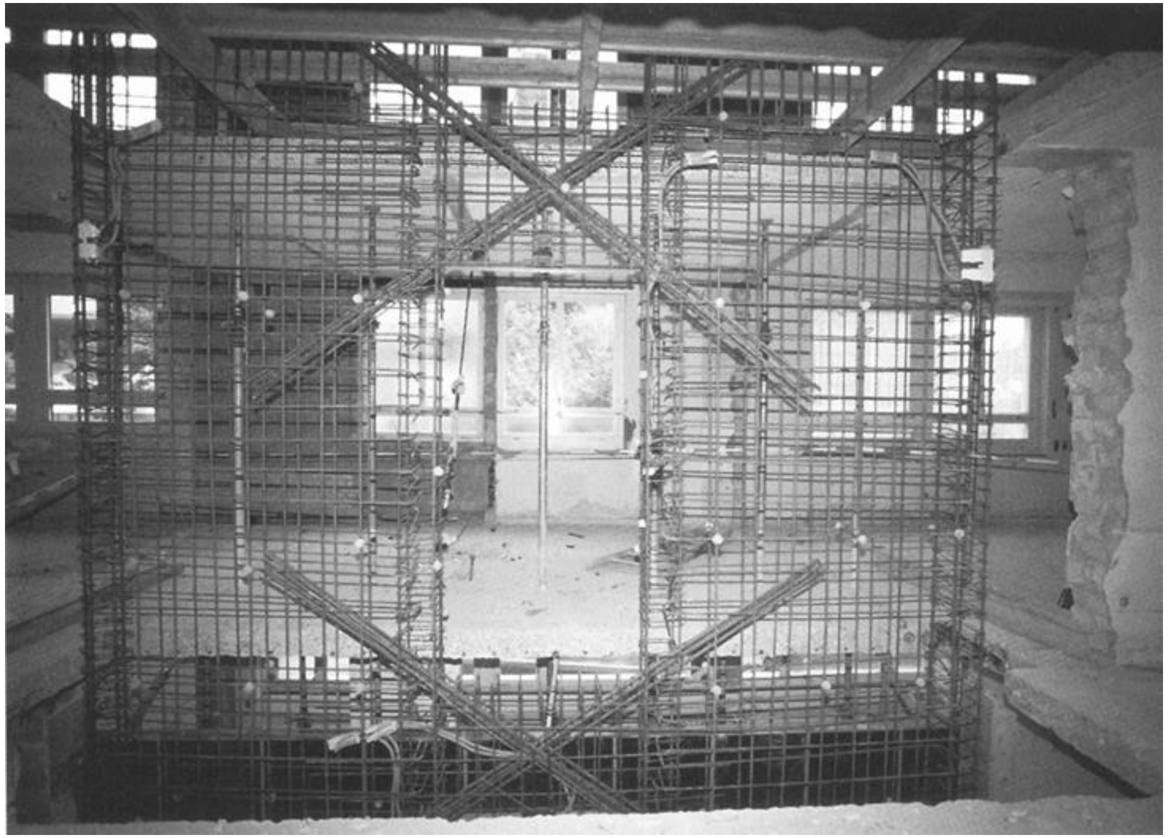
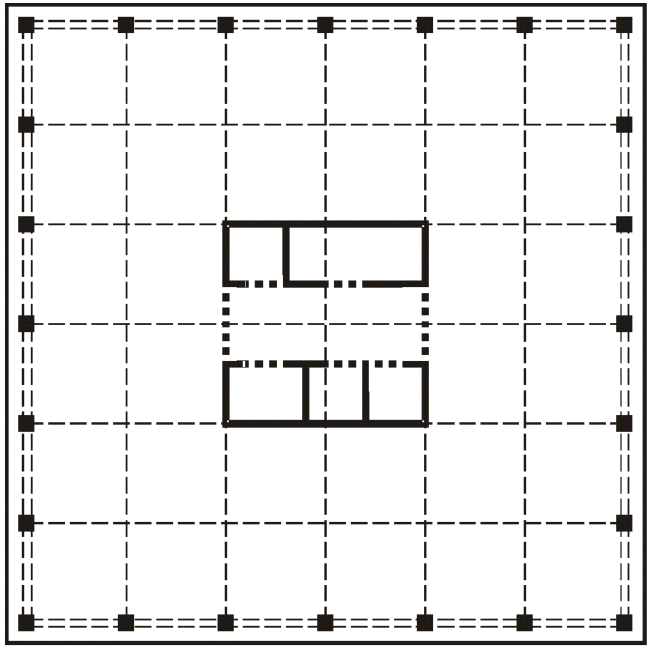
Buildings with coupled RC walls



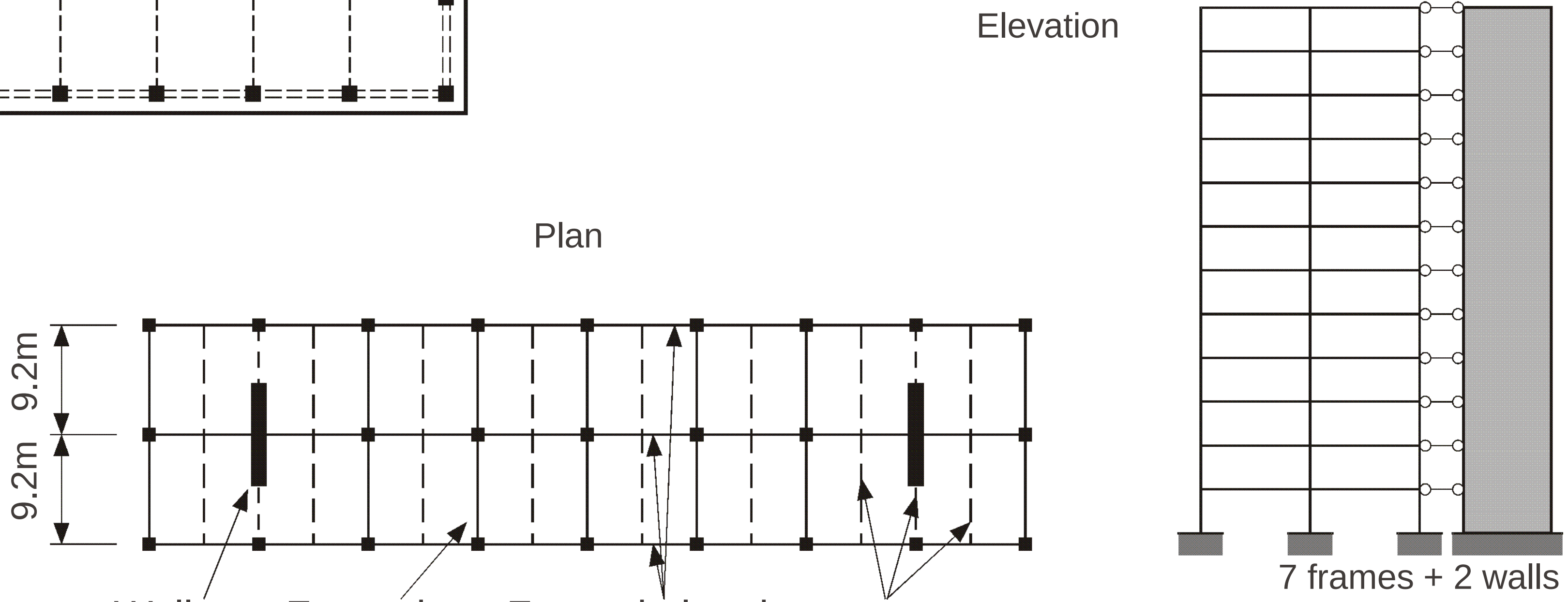
Strengthening of the children's hospital in Aarau (Switzerland) by means of RC walls coupled by deep beams with diagonal reinforcement

Dual wall-frame systems

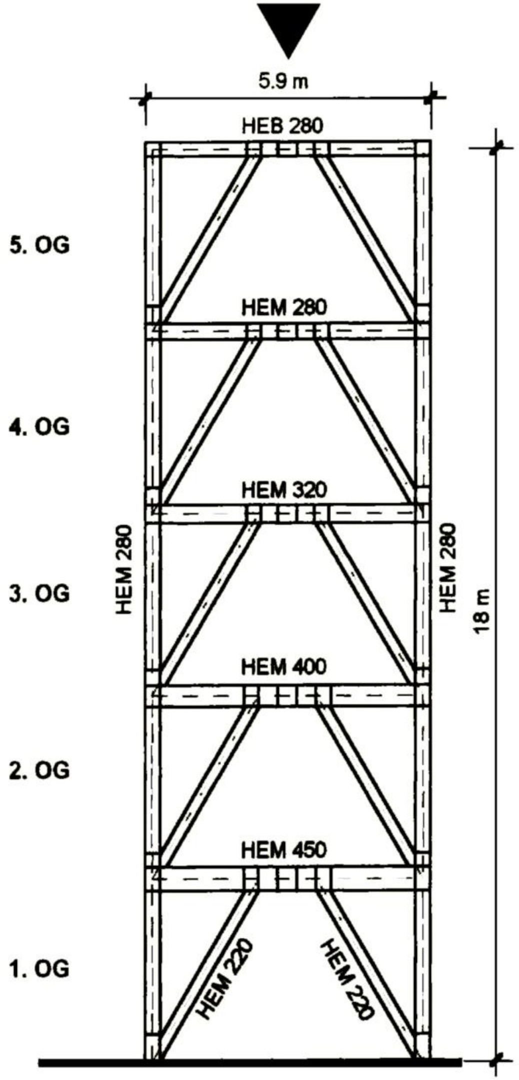


„Tube in Tube“ system

Classical dual system

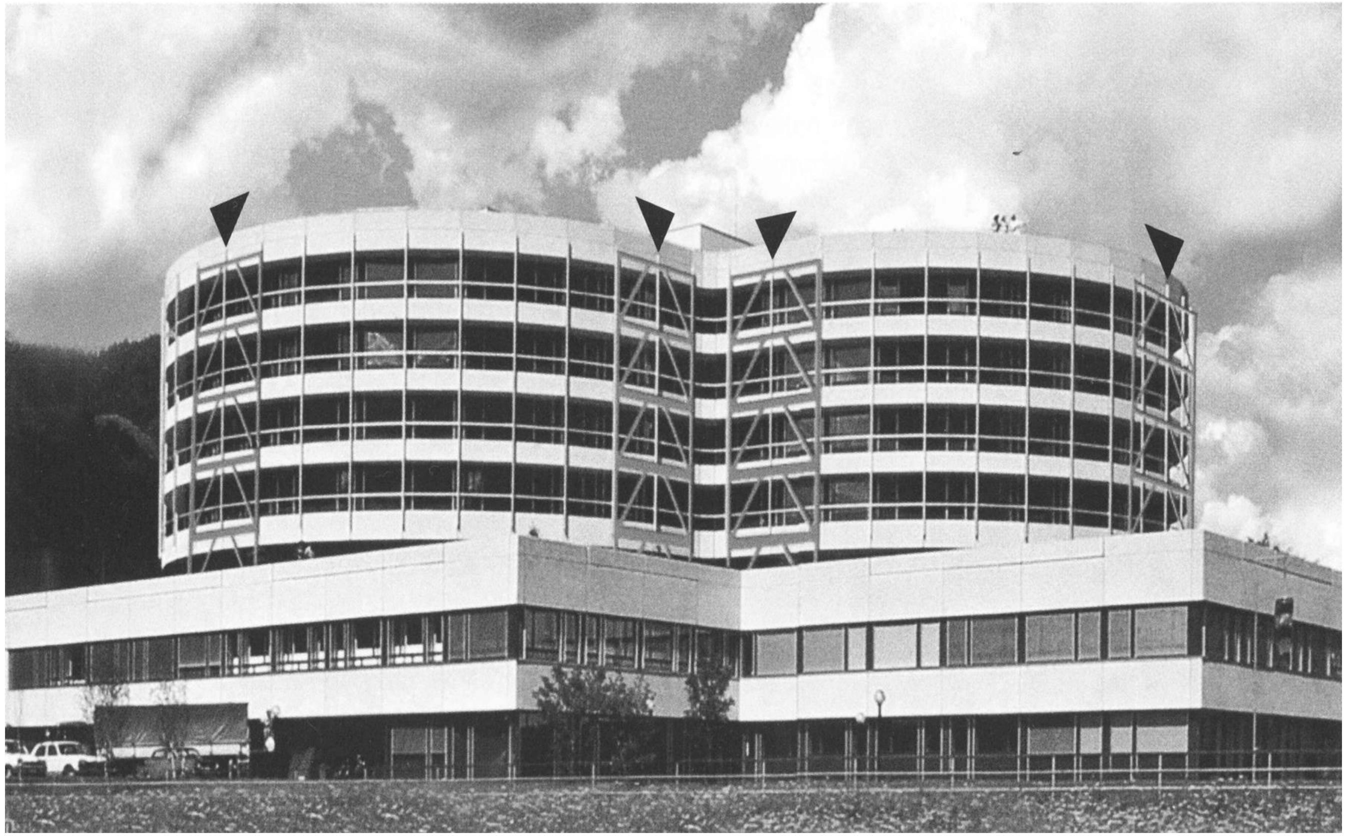


Steel truss with eccentric bracing



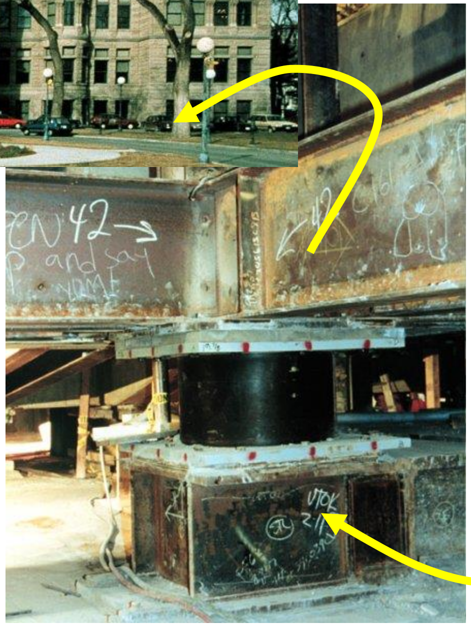
Children's hospital in Brig

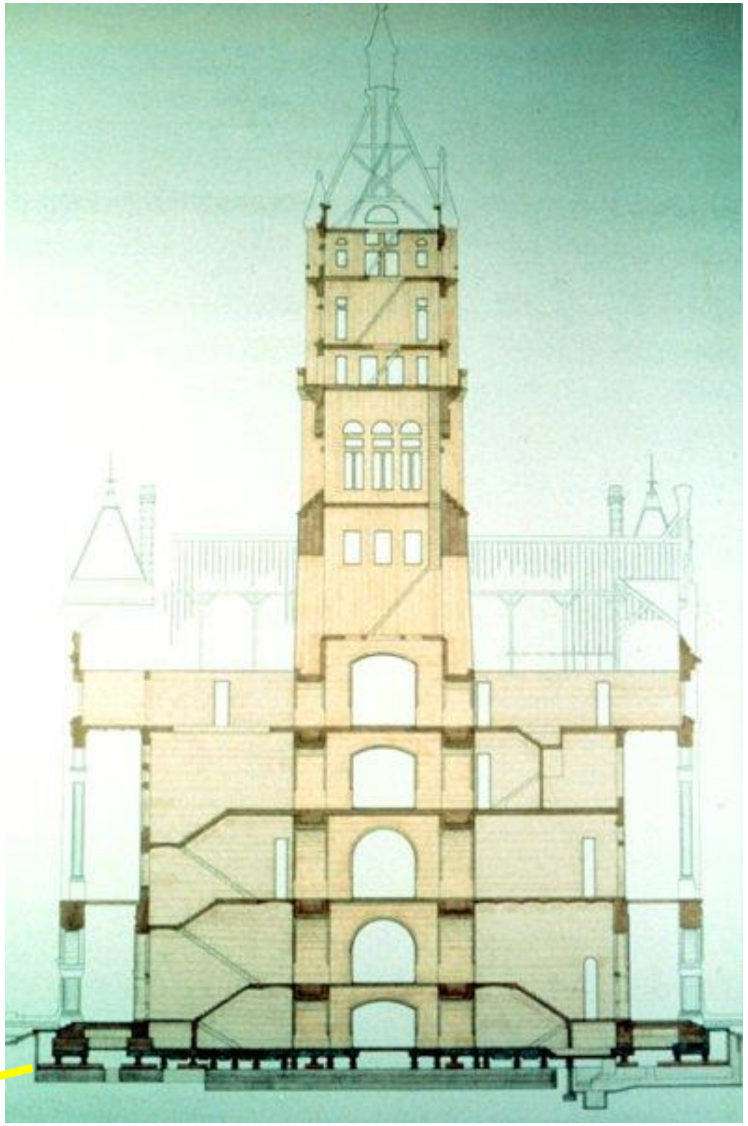
Seismic strengthening with ductile steel frames with eccentric bracing



© P. Tissierès

Base isolation of structures





For example:

- Rubber bearing reinforced by steel layers
- Pendulum bearing isolators

Base isolated structures

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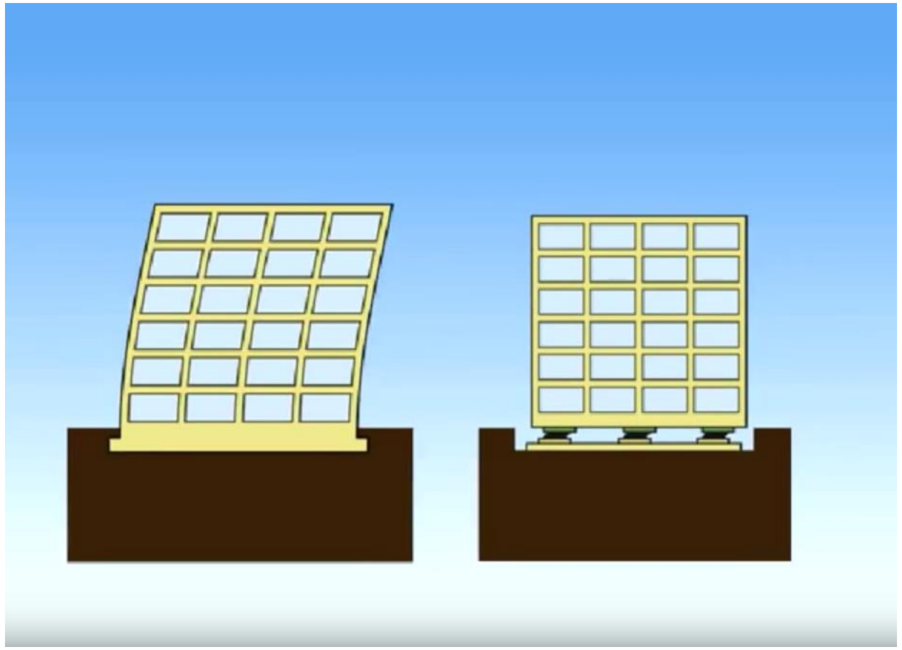
Principal idea of base isolation

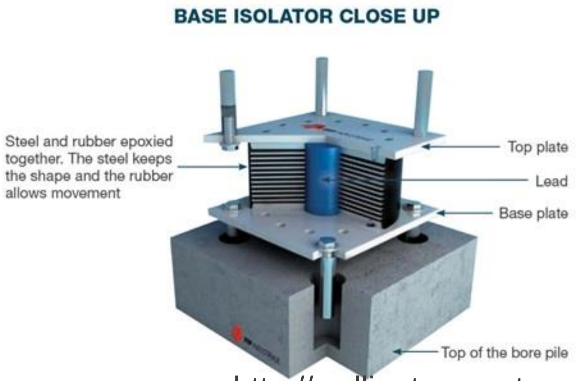
- Concentrate deformation in a soft layer below the structure, which can absorb large deformations (e.g. rubber bearings)



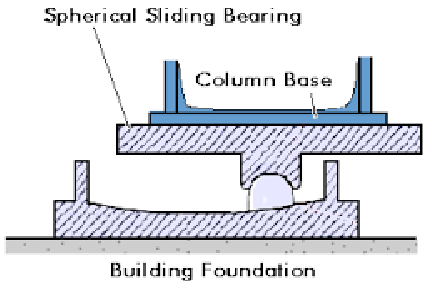
https://www.youtube.com/watch?v=vtT9dN1g770

Video

@ Martina Paronesso, Matteo Realini, Jean-Paul Previero



http://wellington.govt.nz



For a building that you choose

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Goal: Discuss the expected seismic response for a building of your interest.

Task: Present in one slide (in groups of 2) and submit as pdf on moodle until Friday 28.2.2025

- Photos
- Construction year (if known)
- Location
- Structural system (if known)
- Structural material (if known)
- Anything else you think important

RC frames with masonry infills

Seismic behaviour of RC frames with masonry infills

→ Video on moodle «Seismic behaviour of RC frames with URM infills» (see slides at the end of this course

RC moment resisting frames with URM infills

© U. Yazgan


© H. Bachmann

Slides accompagnying the video on moodle «Seismic behaviour of RC frames with URM infills»

Video duration: 10 min

Instructions: Watch video before completing this week’s quiz

RC frames with unreinforced masonry infills

Unreinforced masonry infills

- Typically considered as a non-structural element
- Out-of-plane failure due to accelerations
- Accelerations are largest at the top of a building

RC frames with masonry infills

RC frames with masonry infills

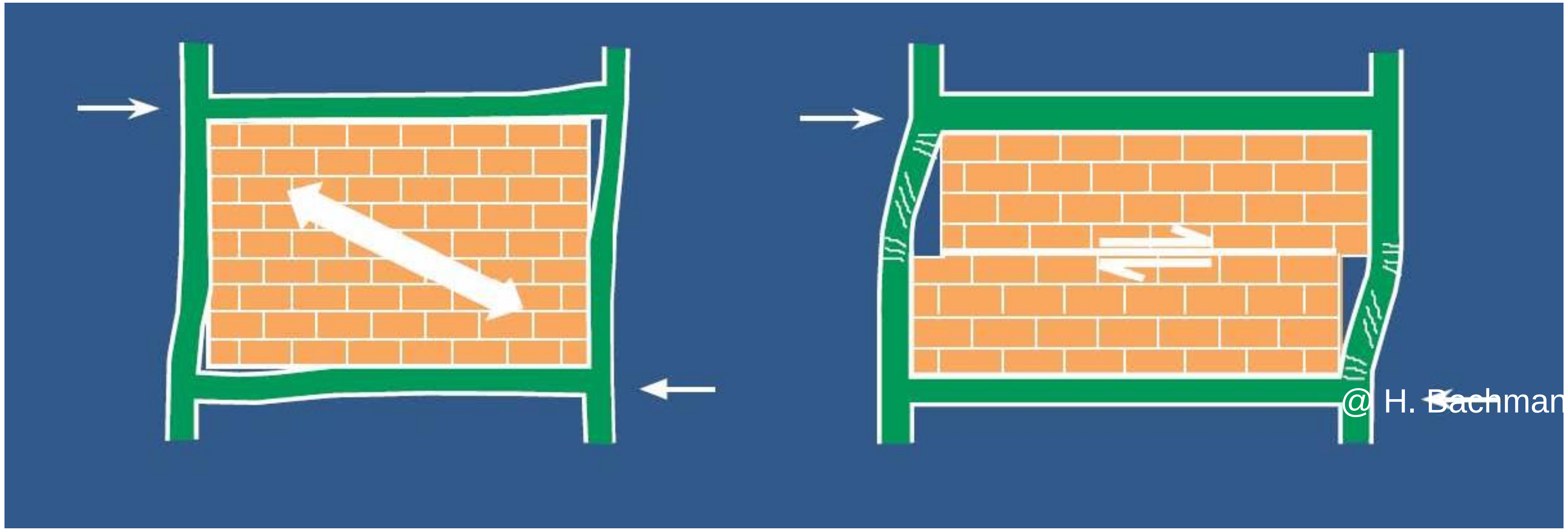
RC frames with masonry infills

Interaction of RC frame with masonry infills

→ In-plane cracks reduce out-of-plane capacity of infill
→ In-plane damage in infills is largest where drift of frame is largest (bottom of the building)
→ Out-of-plane failure not necessarily at the top of the building where accelerations are largest but at the bottom or at mid-height of the building where the ratio of demand / capacity is highest

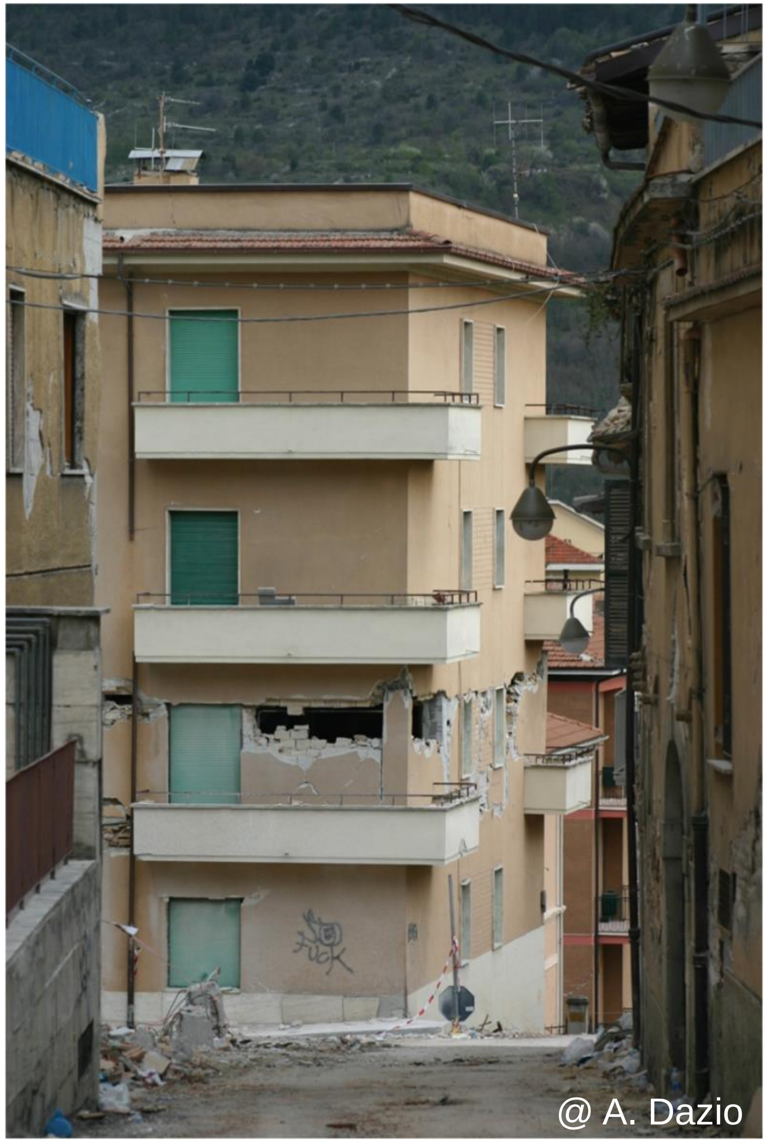
RC frames with masonry infills

Pay attention to interaction between masonry infills and RC frames!



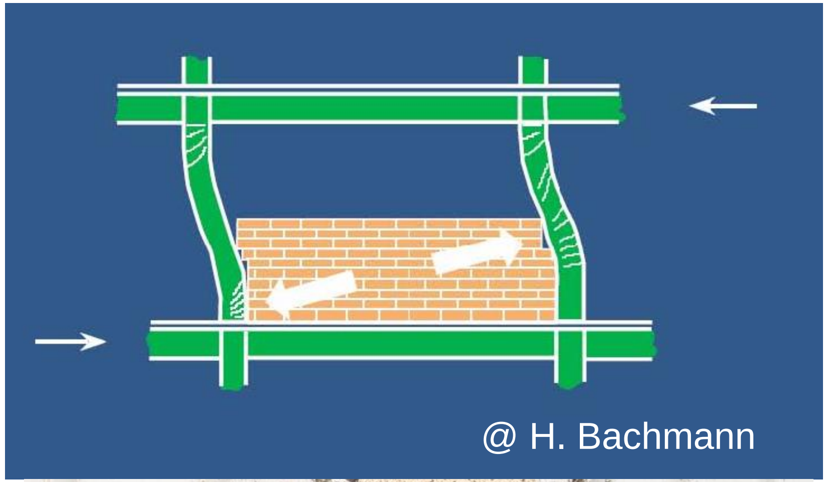
- Masonry infill:
  - Structural or non-structural element?
  - Often considered as non-structural element but it can influence the structural response (stiffness of the infill is of the same order of magnitude as the stiffness of the frame)

RC frames with masonry infills



RC frames with masonry infills

Avoid partially infilled frames!


@ H. Bachmann


@ A. Dazio


@ A. Dazio

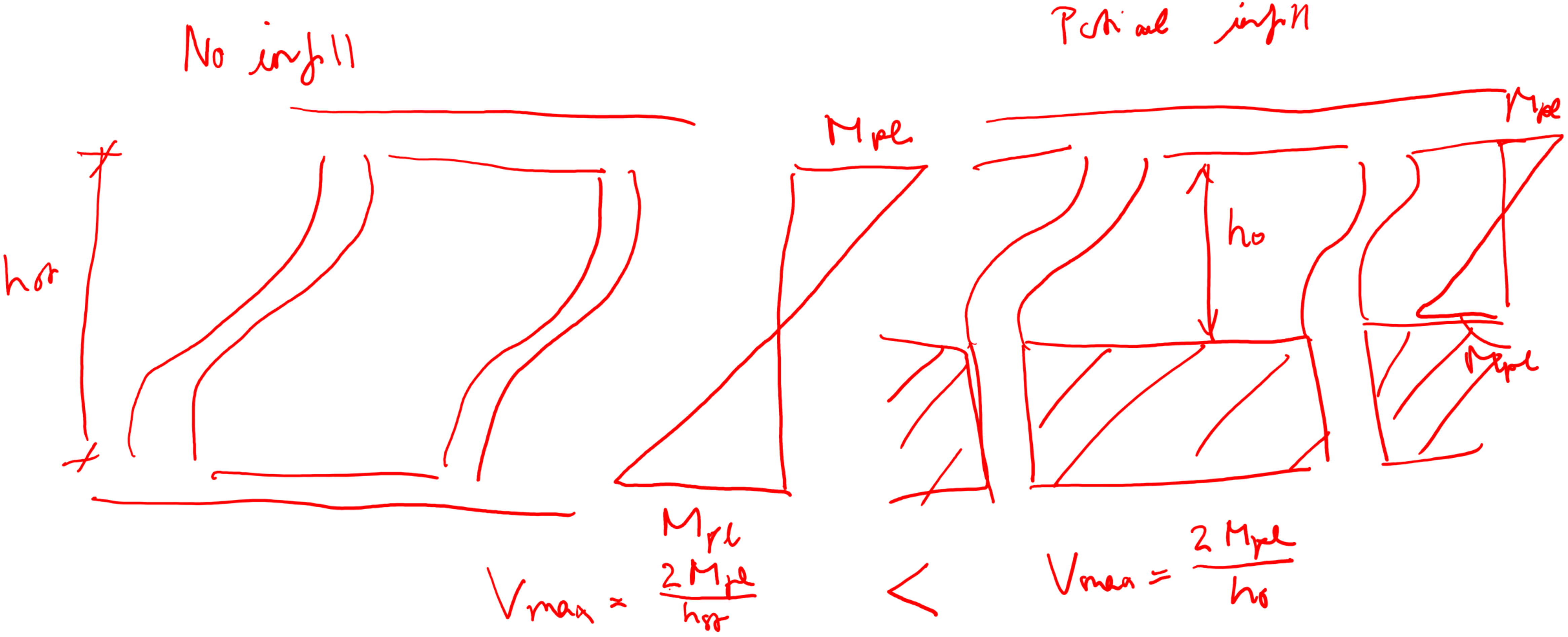
RC frames with masonry infills

Partially infilled RC frames: Why are they prone to shear failure?

RC frames with masonry infills

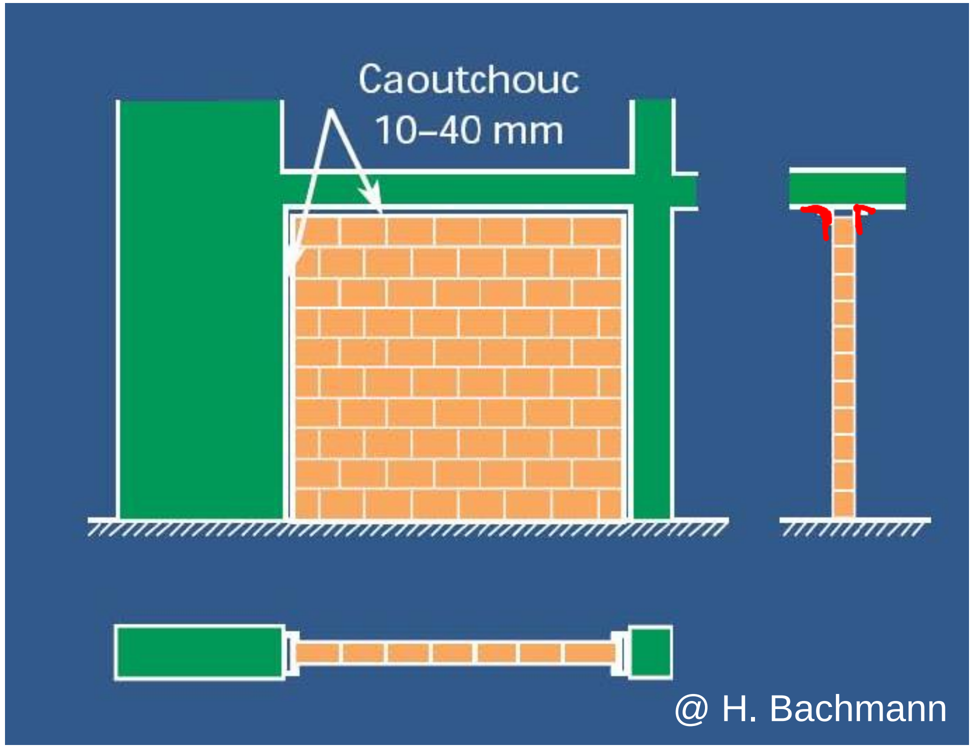
Dr. Igor Tomić

Partially infilled RC frames: Why are they prone to shear failure?



RC frames with masonry infills

If the masonry infill is conceived as non-structural component, it should be separated from the wall:



- Separate the infill wall from the structural elements by a joint (fill the joint with rubber).
- Stabilise the infill so that it does not fall out due to the out-of-plane accelerations.

Annex

RC wall buildings

Dr. Igor Tomić

- RC wall buildings

- Ductile failure mechanism of RC walls:
  - Flexural hinge at the base of the wall

- Brittle failure mechanism:
  - Compression failure of unconfined concrete
  - Shear failure (failure of compression diagonal or shear reinforcement)

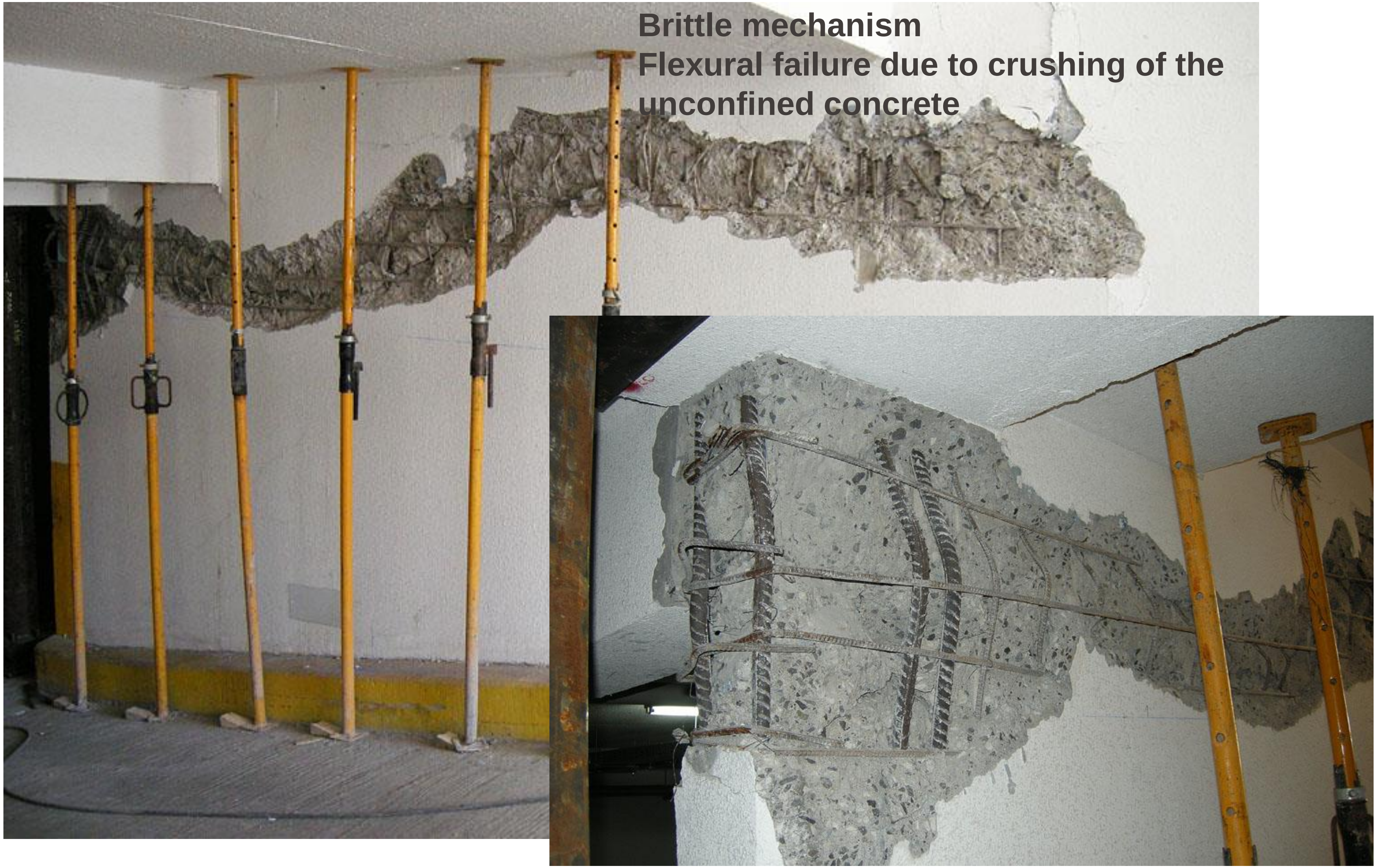
RC wall buildings

Concepcion, 152 Castellon (Chile)

RC wall buildings

Brittle mechanism

Flexural failure due to crushing of the unconfined concrete



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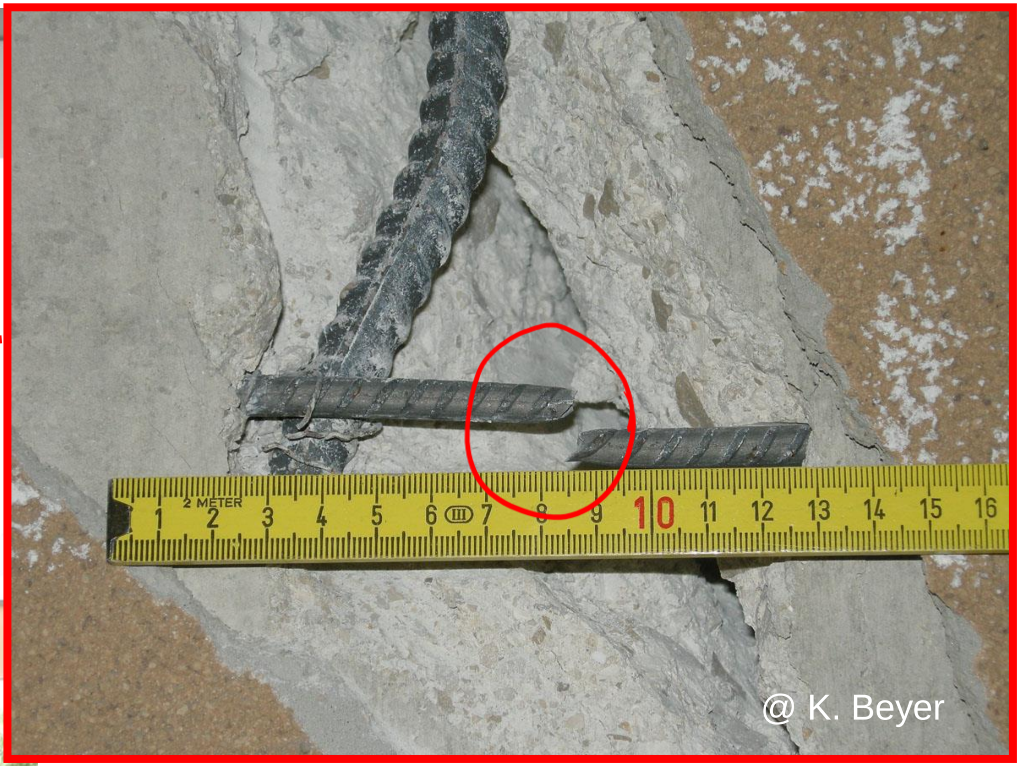
RC building with different bracing systems for the two directions: Frames in the short direction and walls in the long direction

Via Svizzera
@ A. Dazio

RC wall buildings



Shear failure: Diagonal crack and rupture of the horizontal reinforcement

Via Svizzera, L'Aquila

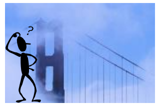
RC wall buildings

Shear failure: Crushing of the compression diagonal

Concepcion, 152 Castellon (Chile)

RC wall buildings

One question...



If I design a building in Switzerland according to the seismic design forces specified in the Swiss code, which of the following statements is correct?

A. It is safe in the event of any earthquake.

B. It is safe in the event of most earthquake scenarios for Switzerland.

C. It is safe if ground motions of the order of the Basel earthquake from 1356 would be repeated.