RC sandwich walls subjected to seismic loads

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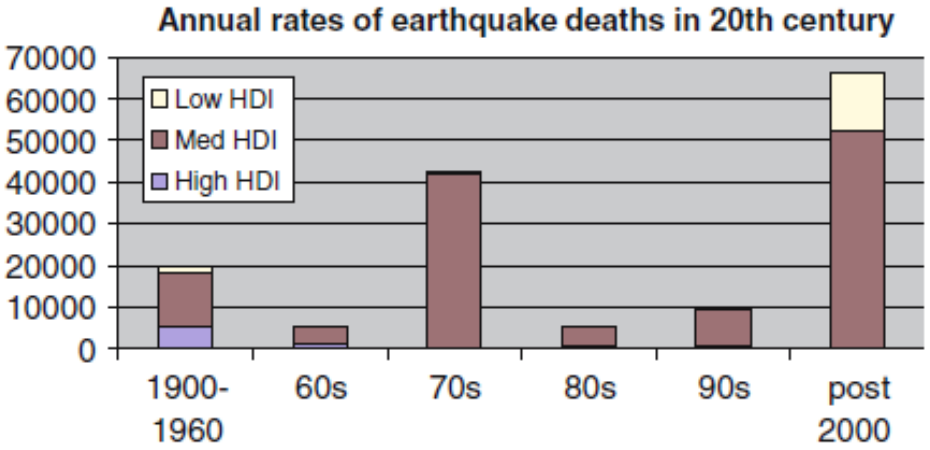
The issue

Too many human lives lost due to earthquakes

- On average **40.000** human lives lost per year due to earthquakes in 1990-2010 (USGS)

- During 2008 Sichuan (China) earthquake **5200 students** died due to the collapse of school (low-rise) buildings



Spence 2007

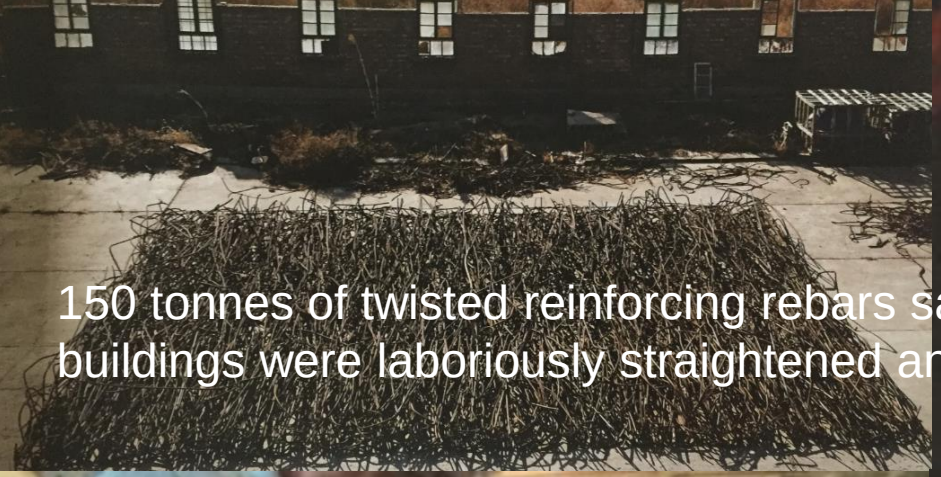
Schools are particularly vulnerable

- Artist **Ai Weiwei** expressed the disastrous event of the 2008 Sichuan earthquake with his artpiece "**Straight**" (Venice 2013,Brooklin Museum 2014, Royal Academy London 2015

- **150 tonnes** of twisted reinforcing rebars savaged from collapsed school (frame) buildings were laboriously straightened and stacked in to a fissured landscape, accompanied by the list of more than **5000** names of lost children.

Ai Weiwei @ the Royal Academy London, Nov. 2015

Straight

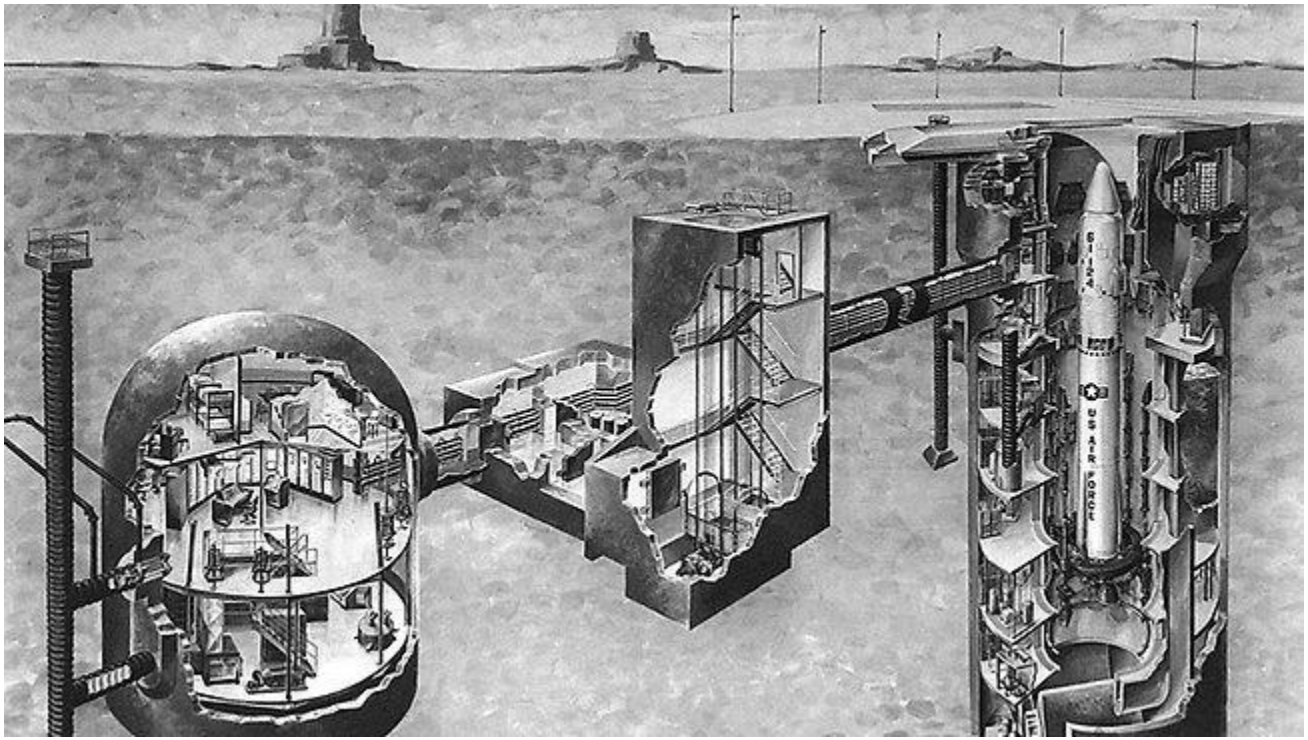


150 tonnes of twisted reinforcing rebars savaged from collapsed school (frame) buildings were laboriously straightened and stacked in to a fissured landscape,


accompanied by the list of more than 5000 names of lost children

The challenge: can **we** do something?

Can **we** obtain no-damage & 100% safe buildings against earthquake («seismic proof building»)



Wall (masonry structures) have been used for thousands of years

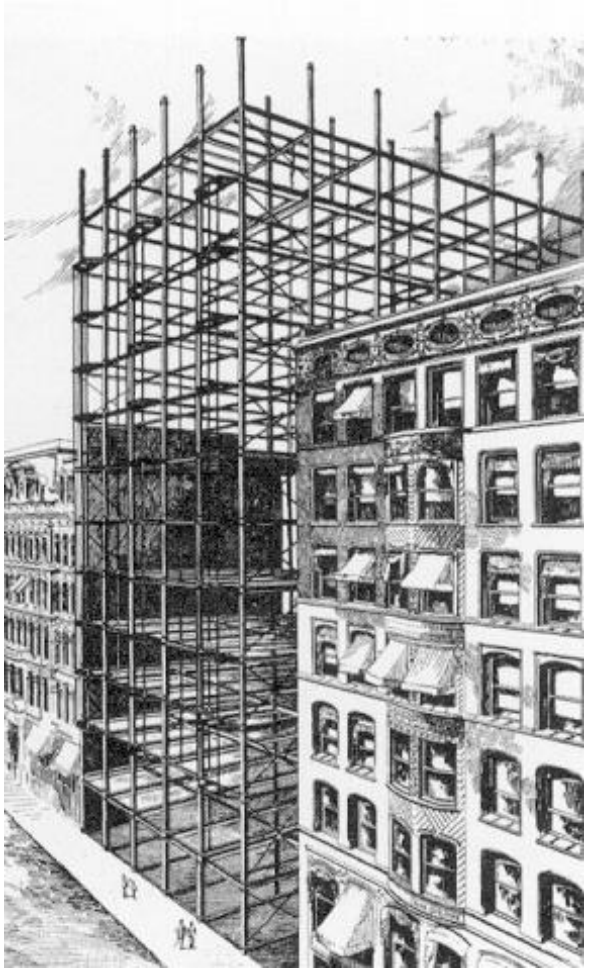
Ziqqurat

Nuraghe

Palazzo Strozzi

From masonry wall structures to frames

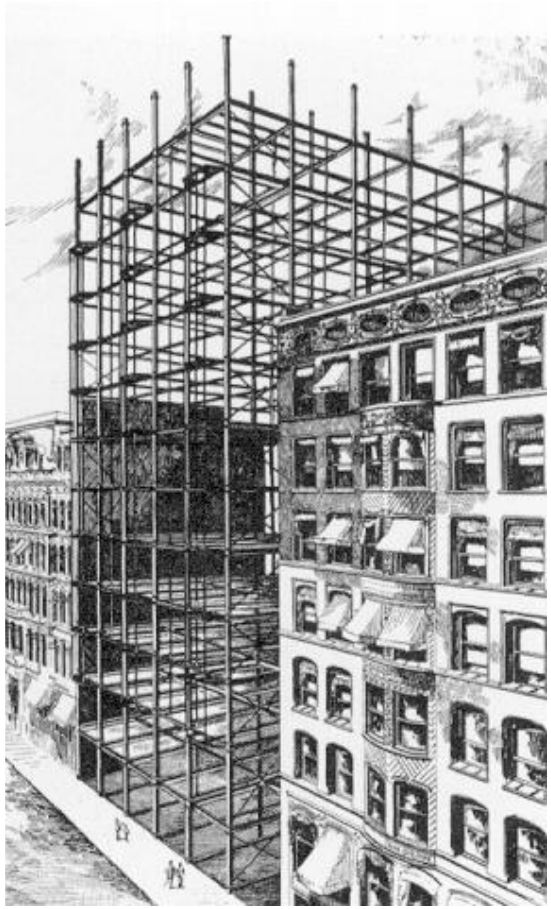
Monadnock , Chicago, 1891



Unity Building (Clinton Warren, 1892)

First framed structures

Separation and freedom



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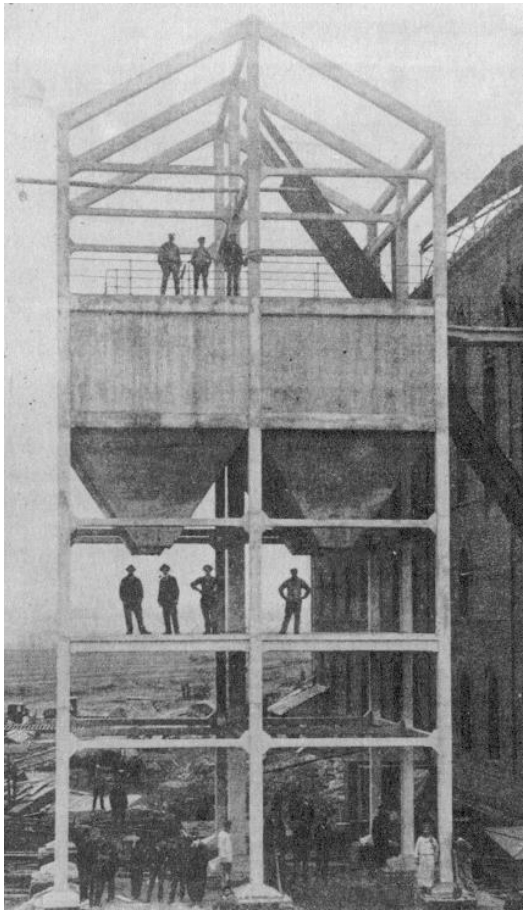
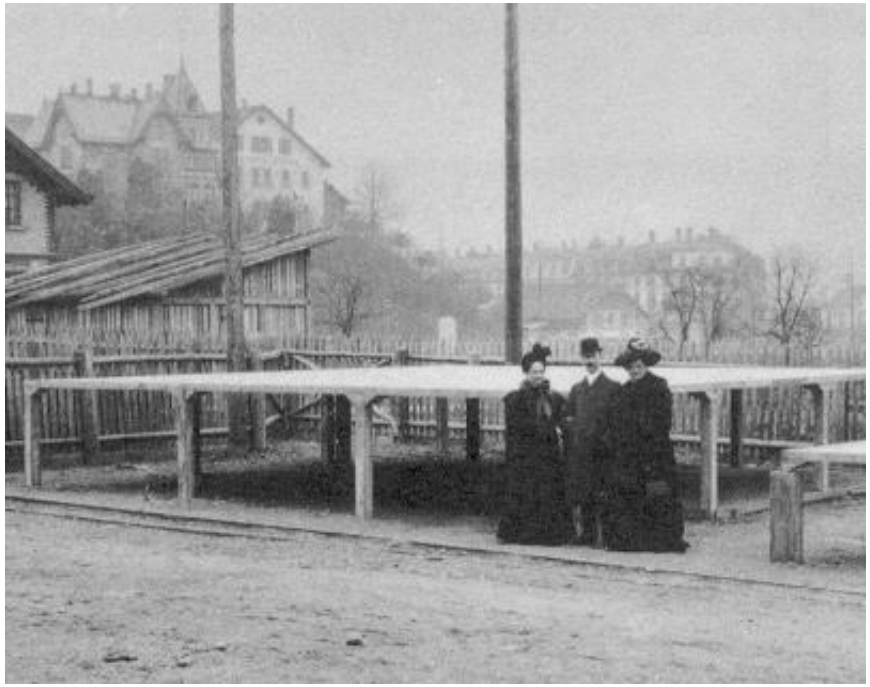


RC Silo, Aniche(Francois Hennebique)

Framed structures

Intrinsic limited lateral strength



RC frame, Zurich, 1906

Robert Maillart

Traditional approach to seismic design: ductile structure, but ductility = damage

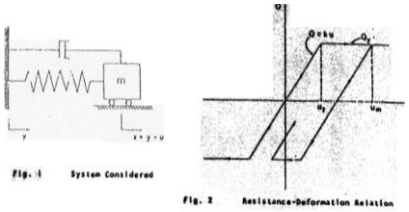
Japan – 1956

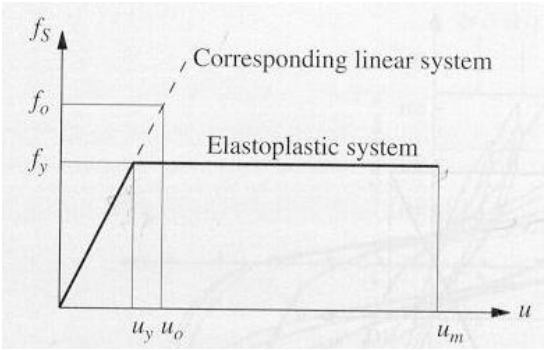
Also available in "Selected Papers by N. M. Newmark", Civil Engrng Classics, ASCE, 1976

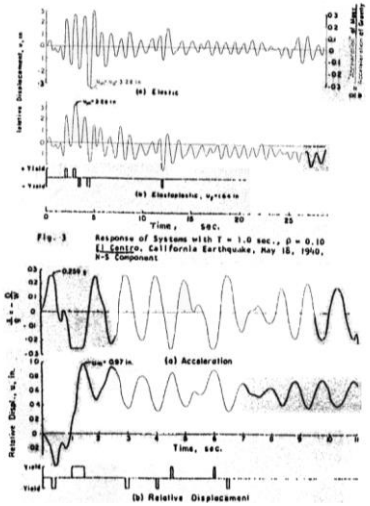
EFFECT OF INELASTIC BEHAVIOR ON THE RESPONSE OF SIMPLE SYSTEMS TO EARTHQUAKE MOTIONS

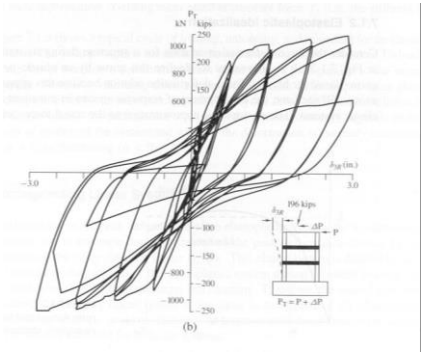
by

A. S. Veletsos* and N. M. Newmark**

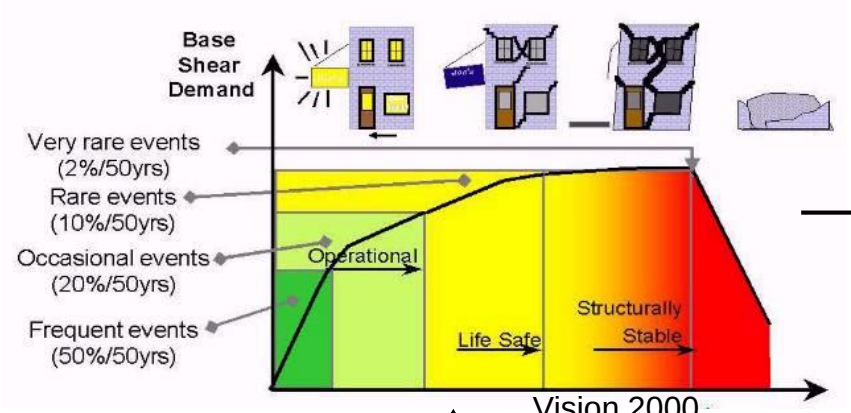




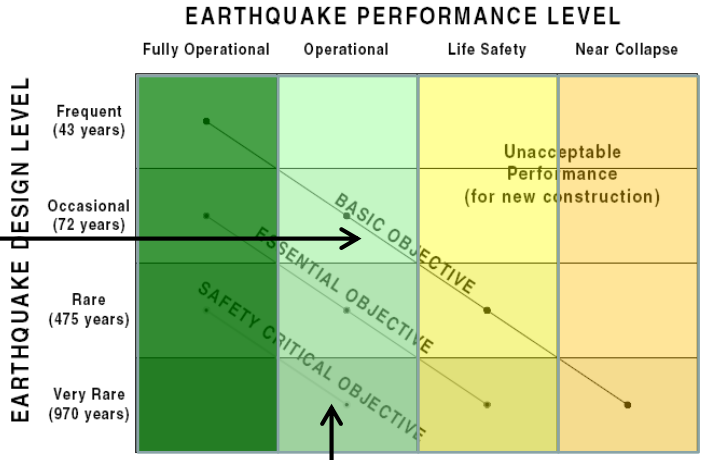




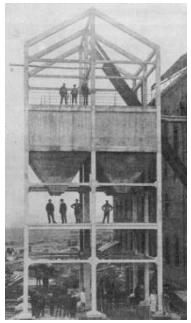
Current earthquake engineering performance objectives are limited for traditional (frame) structures due to reduced strength of frame structures

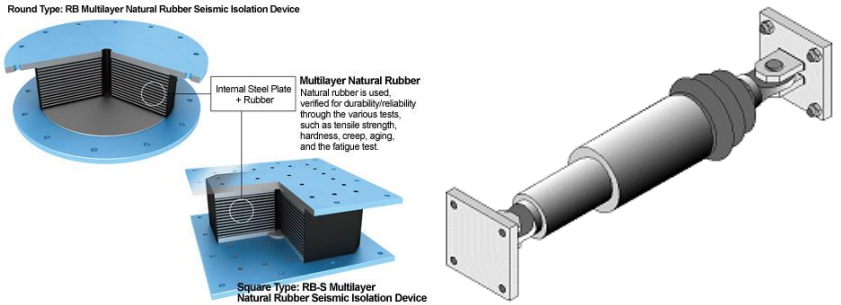


Vision 2000



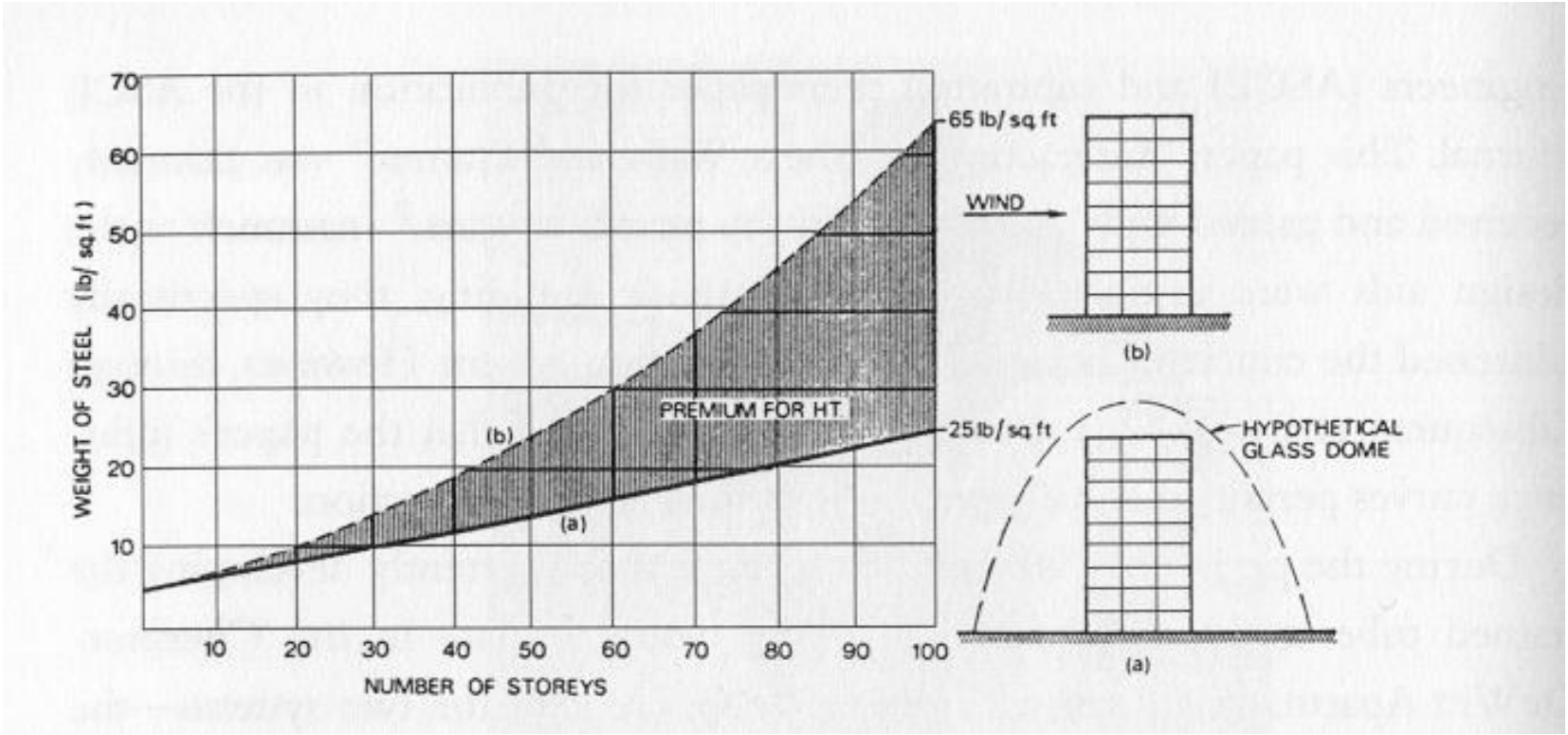
Recommended minimum seismic performance design objectives for buildings





What about making structures that are strong w.r.t. horizontal actions?

Fazlur Khan


WEIGHT OF STEEL (lb/sq ft)
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100
NUMBER OF STOREYS
(b)
(a)
PREMIUM FOR HT.
65 lb/sq ft
25 lb/sq ft
WIND
(b)
HYPOTHETICAL
GLASS DOME
(a)

Fazlur Khan

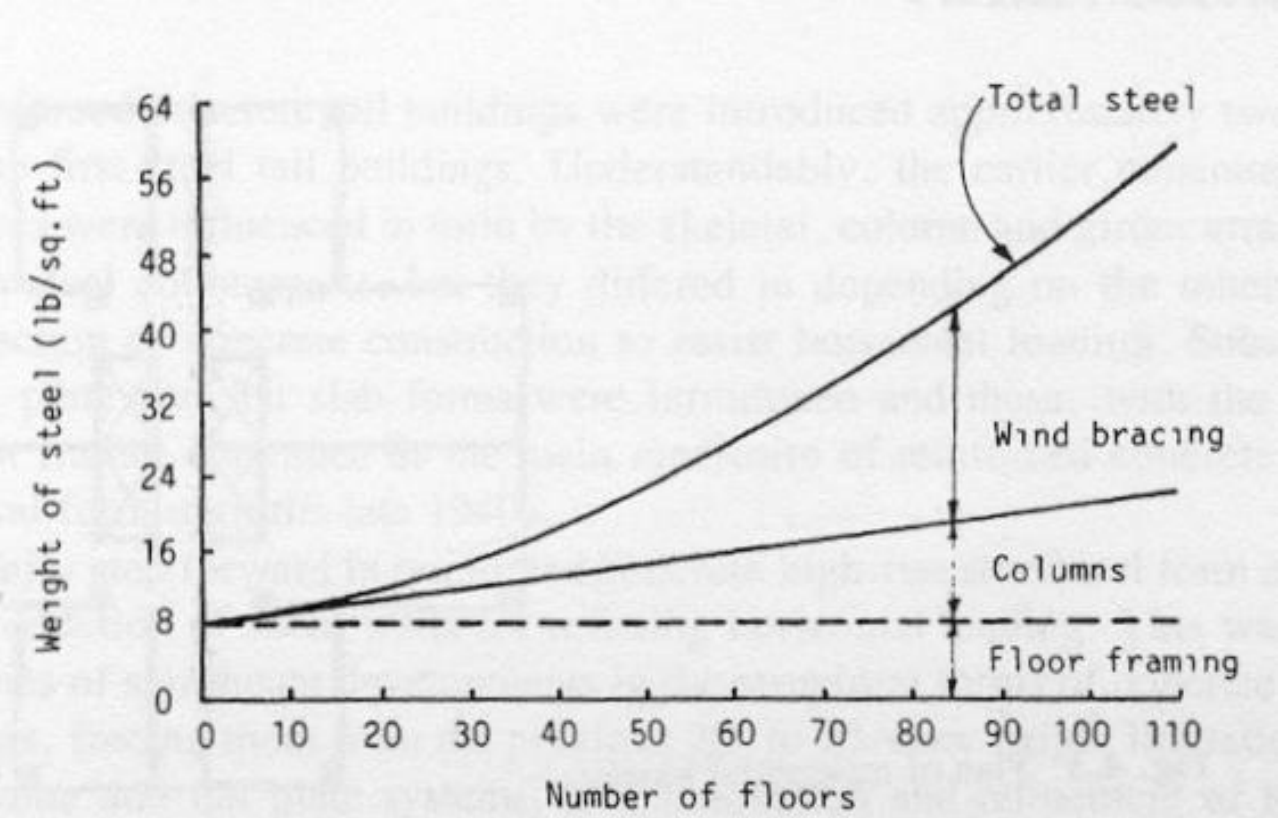
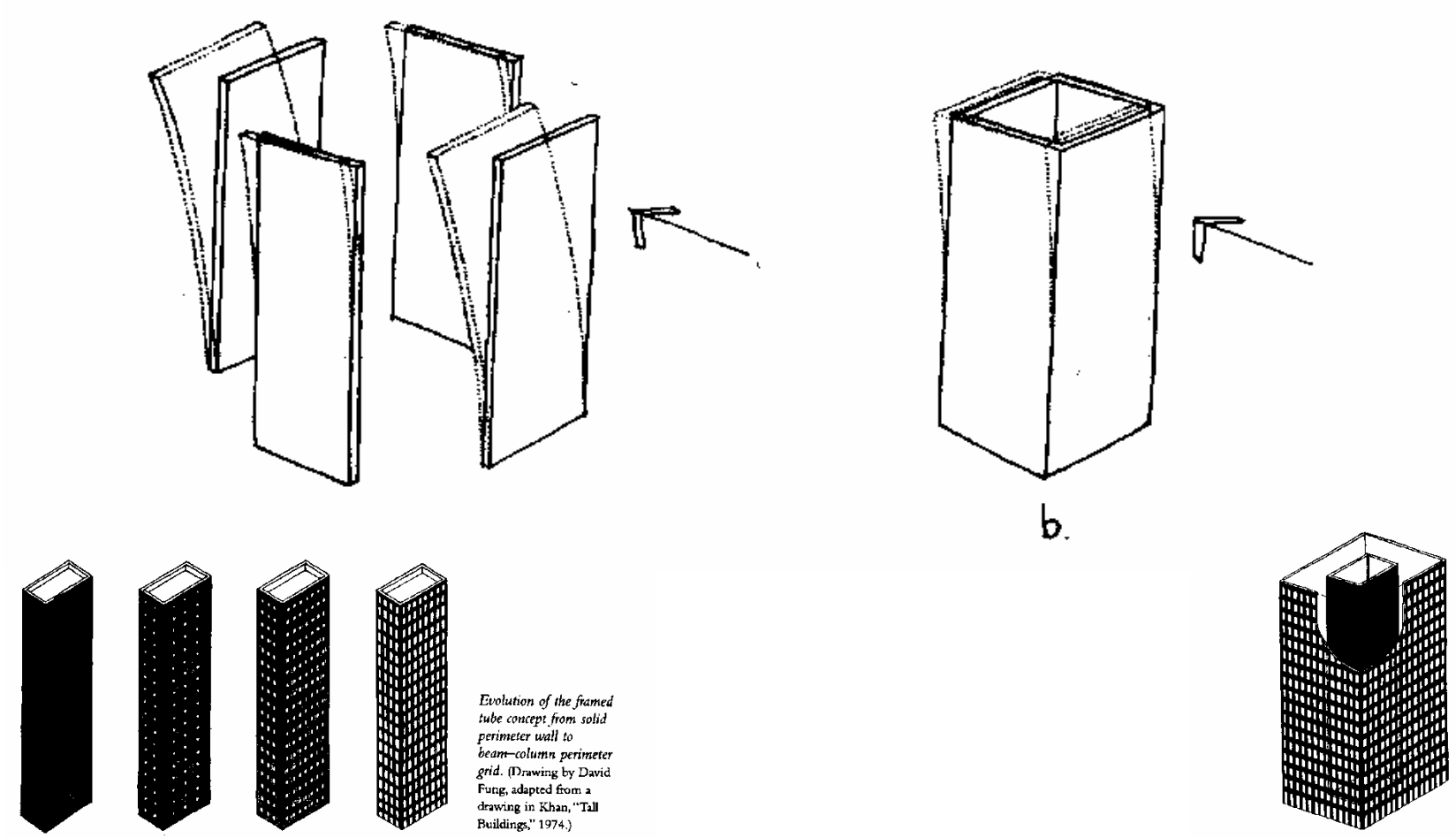


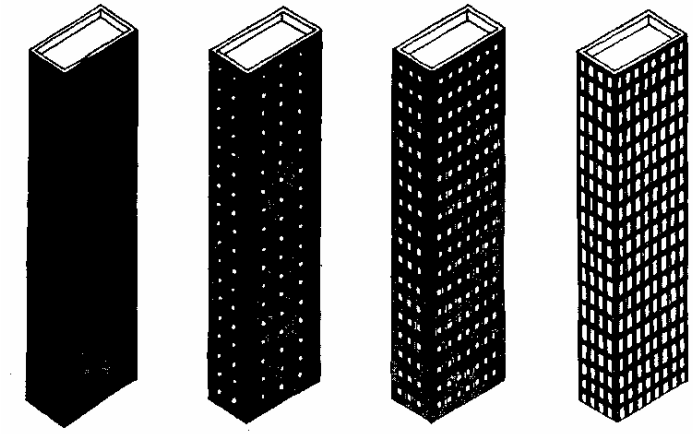
Fig. 4.1 Weight of steel in tall buildings.

Fazlur Khan



Evolution of the framed tube concept from solid perimeter wall to beam–column perimeter grid. (Drawing by David Fung, adapted from a drawing in Khan, "Tall Buildings," 1974.)

Fazlur Khan



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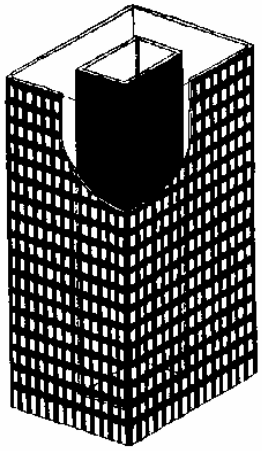
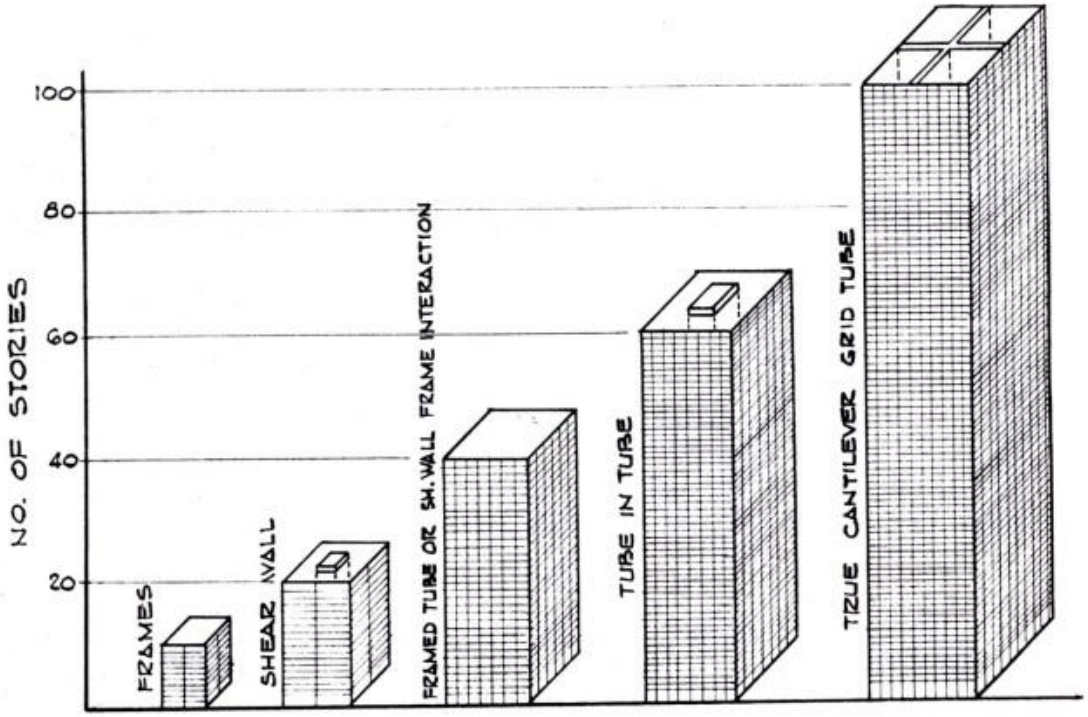
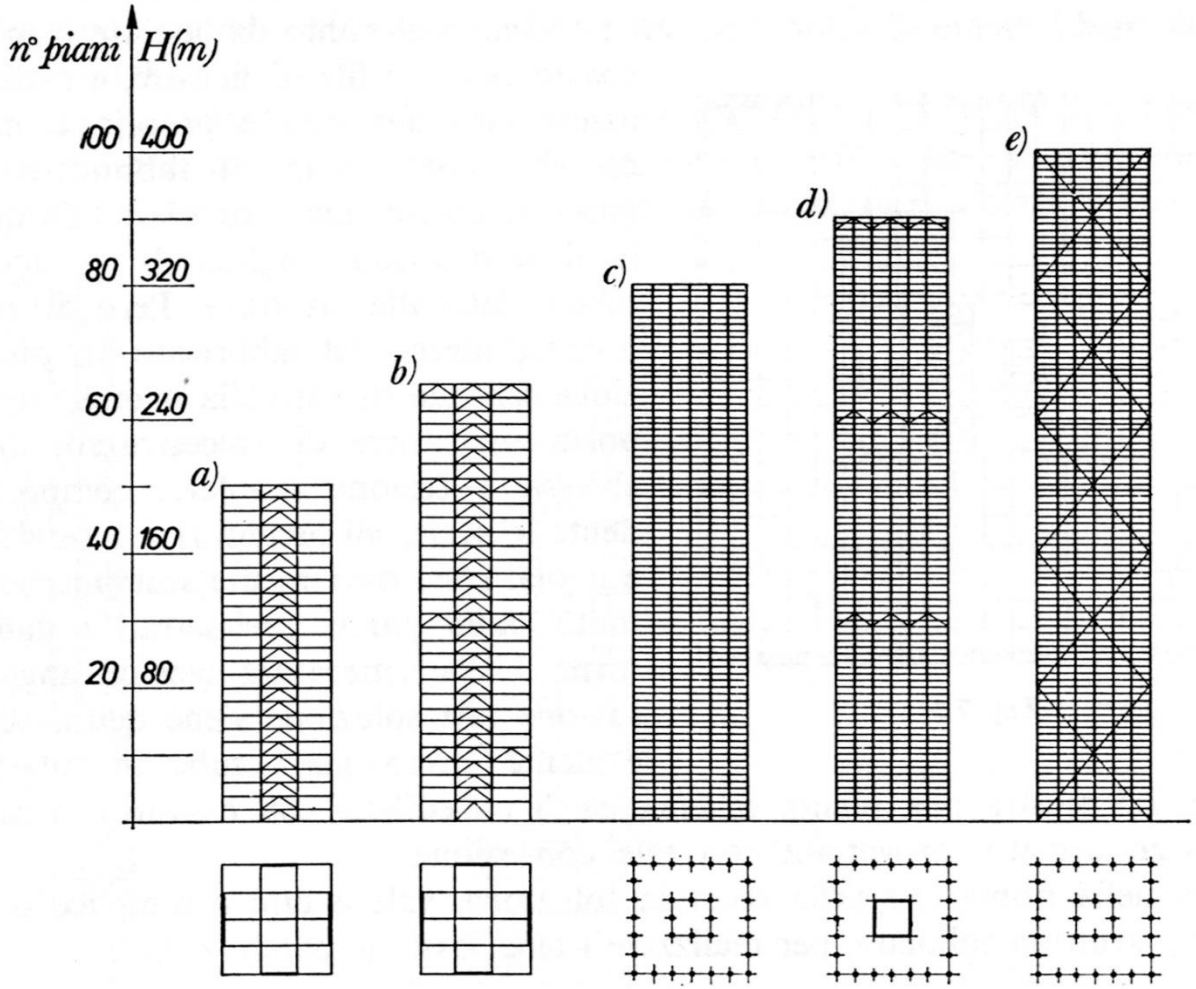


Fazlur Khan

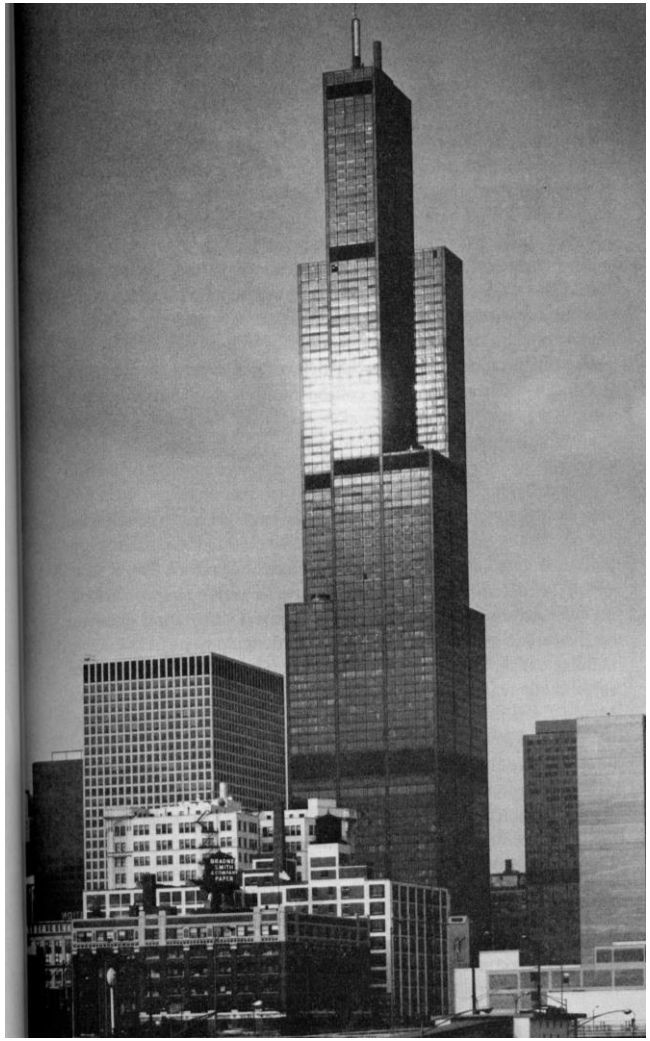


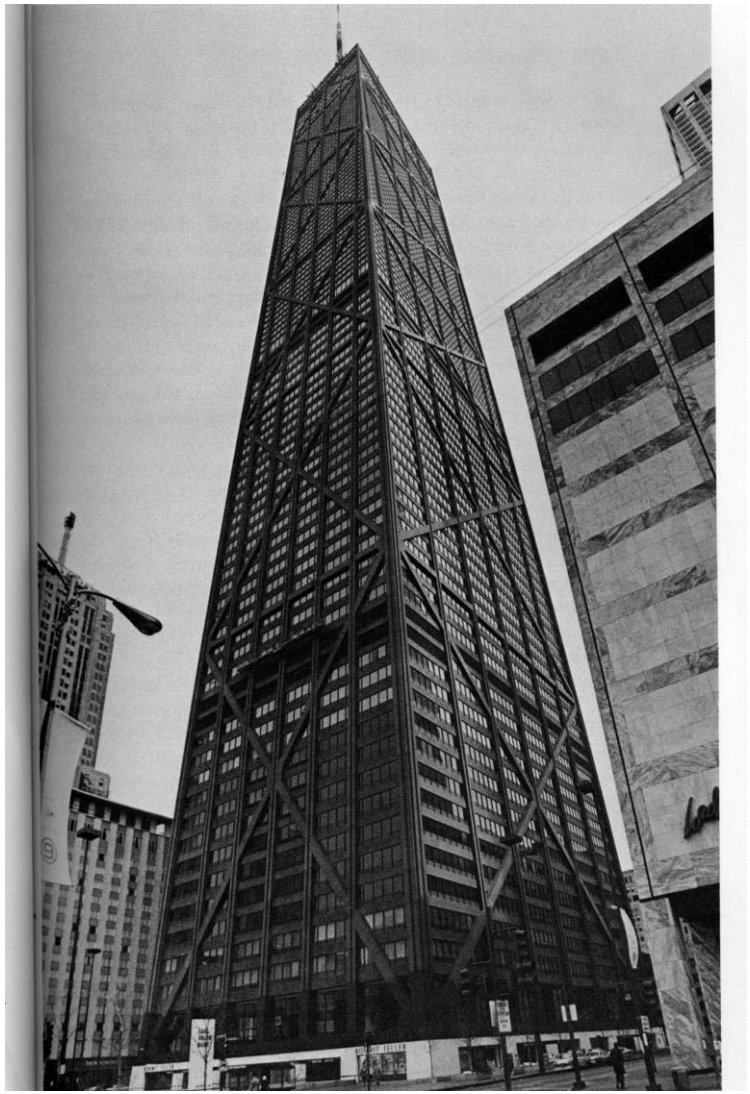
At a tall building symposium in 1966 (proceedings published in Tall Buildings, *1967), Khan demonstrated the dramatic increase in height that could be achieved economically by using a "true cantilever grid tube" structural system.*

Pozzati Ceccoli



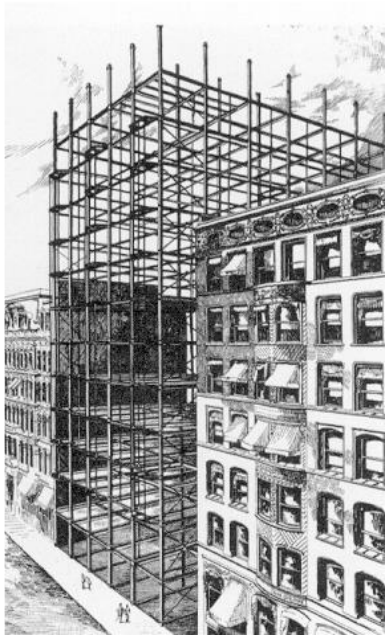
Sears Tower, John Hancock





Going back

What about going back to wall structures but made out of RC?



MIRAMAR (1975 – 21stories)

Performance of Structural Walls in Recent Earthquakes and Tests and Implications for US Building Codes

J. W. Wallace
University of California, Los Angeles, USA

15 WCEE
LISBOA 2012

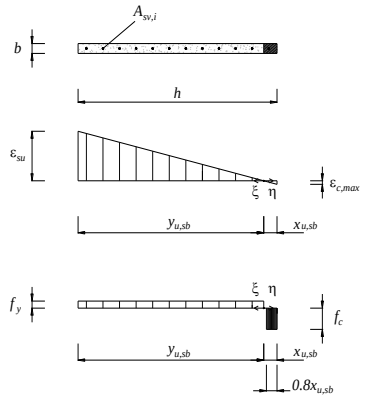
Recent advances in RC wall constructions RC sandwich walls: new techniques are surfacing that allow for easy (and economic) realization + optimal thermal and acoustic performance, what about earthquake performances?

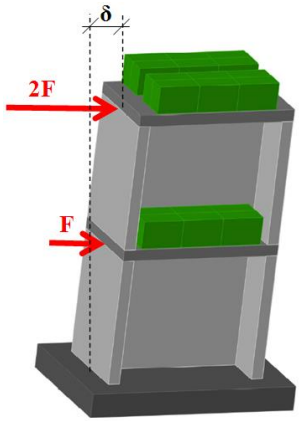
Our studies over the last 15 years

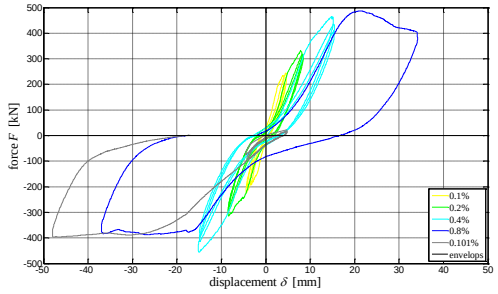
Analytical, numerical and experimental investigations have shown that RC wall structures are characrerized by superior seismic performances that allow for 100 % safe building (no damage)

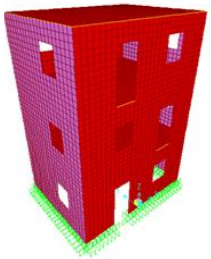
$$M_u = \left(f_y \cdot \rho \cdot b \cdot y_u \right) \cdot \left(\frac{h}{2} - \frac{y_u}{2} \right) +$$

$$+ \left(f_c \cdot b \cdot 0.8 \left(h - y_u \right) \right) \cdot \left(0.1h + 0.4 y_u \right) + A_{s,catena} f_y \left(h - 2c \right)$$



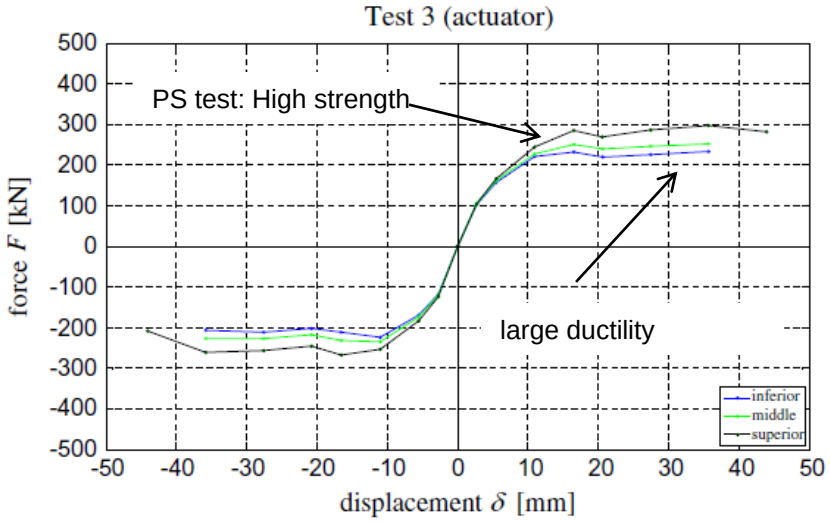


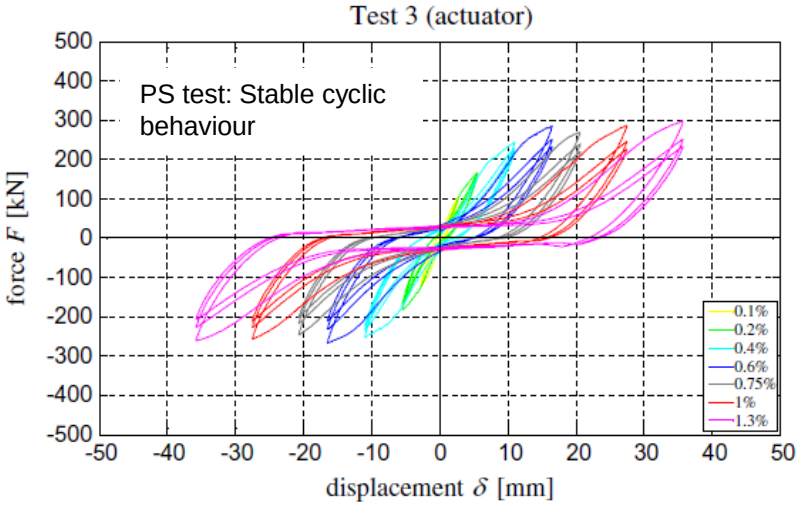




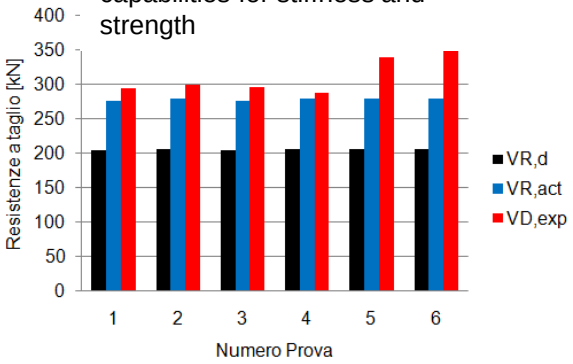
Consolidated results

No damage for design earthquake

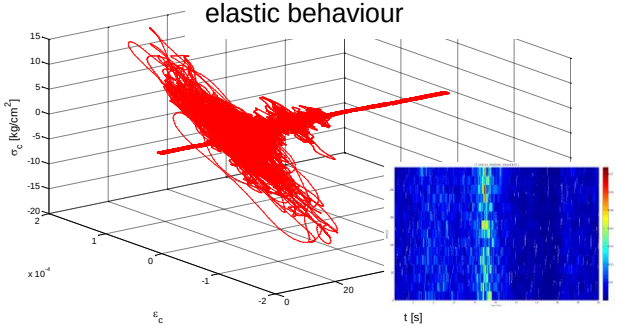




PS test: good predictive capabilities for stiffness and strength



ST test-PGA=1.0g: linear elastic behaviour



Obiettivo n. 2

Progettazione, realizzazione ed interpretazione della **prova su tavola vibrante di una struttura a 3 piani**

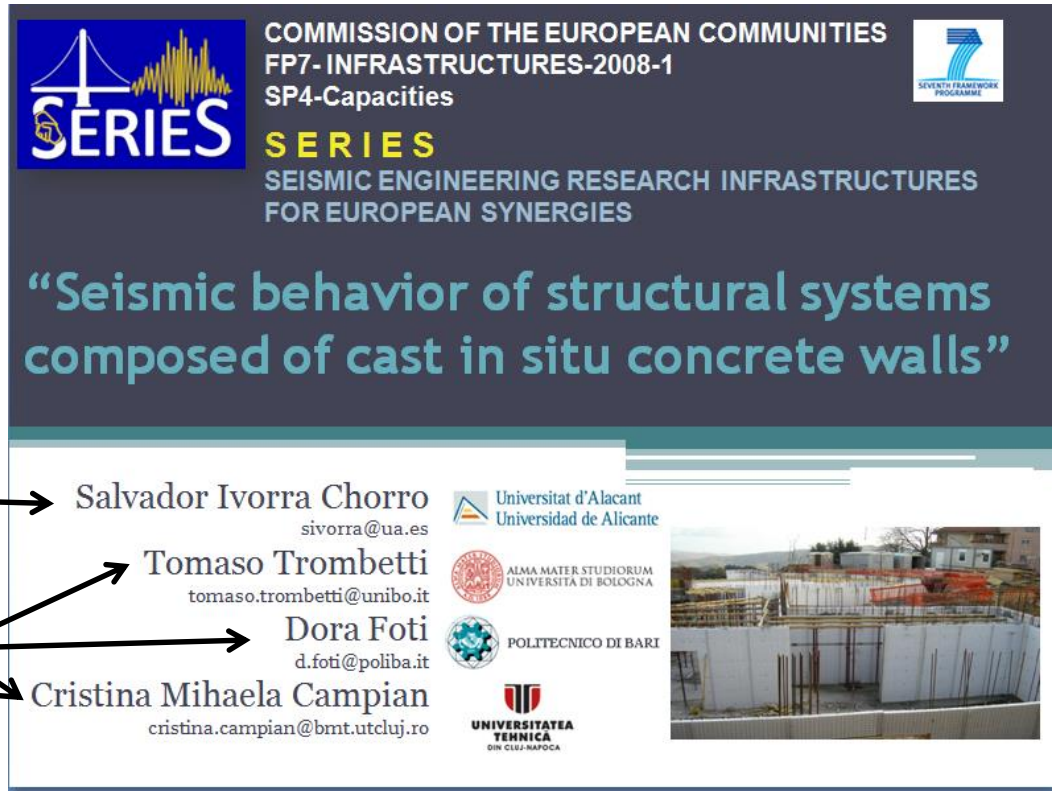
Per validare il **buon comportamento sismico** (già anticipato teoricamente e analiticamente dalle prove pseudostatiche cicliche) delle strutture a pareti sandwich.

SEismic behaviour of structural SYstems composed of cast in situ COncrete WAlls (SE.SY.CO.WA)

Progetto “SERIES” (Seismic Engineering Research Infrastructures for European Synergies)

Lead User

Additional Users



Proposed host TA facility: Laboratory for Training and Research in Earthquake Engineering and Seismology: **EUCENTRE TREES Lab**, Pavia, Italy

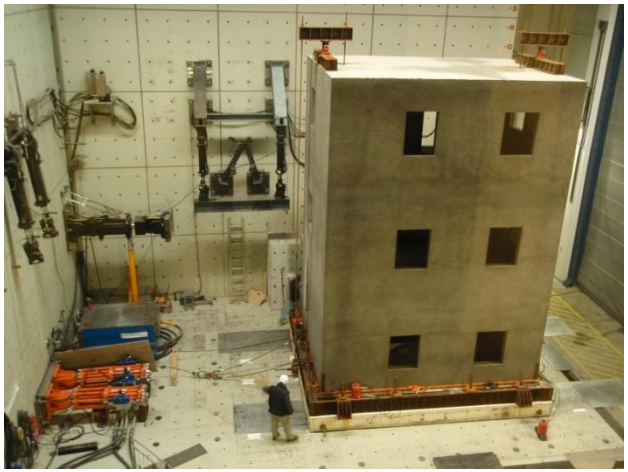
Fasi costruttive

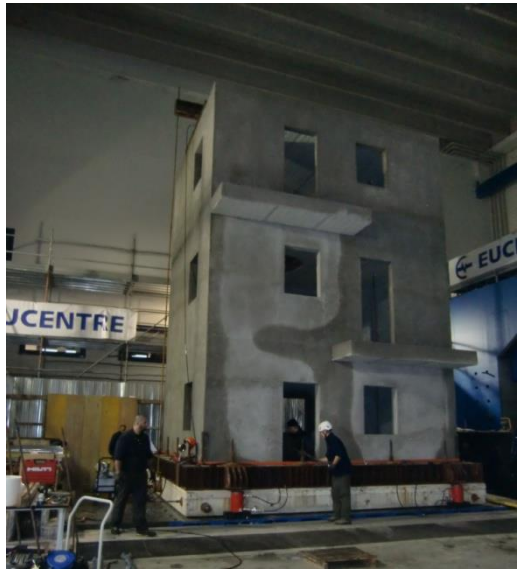
Fasi costruttive

Fasi costruttive

Fasi costruttive

Trasporto

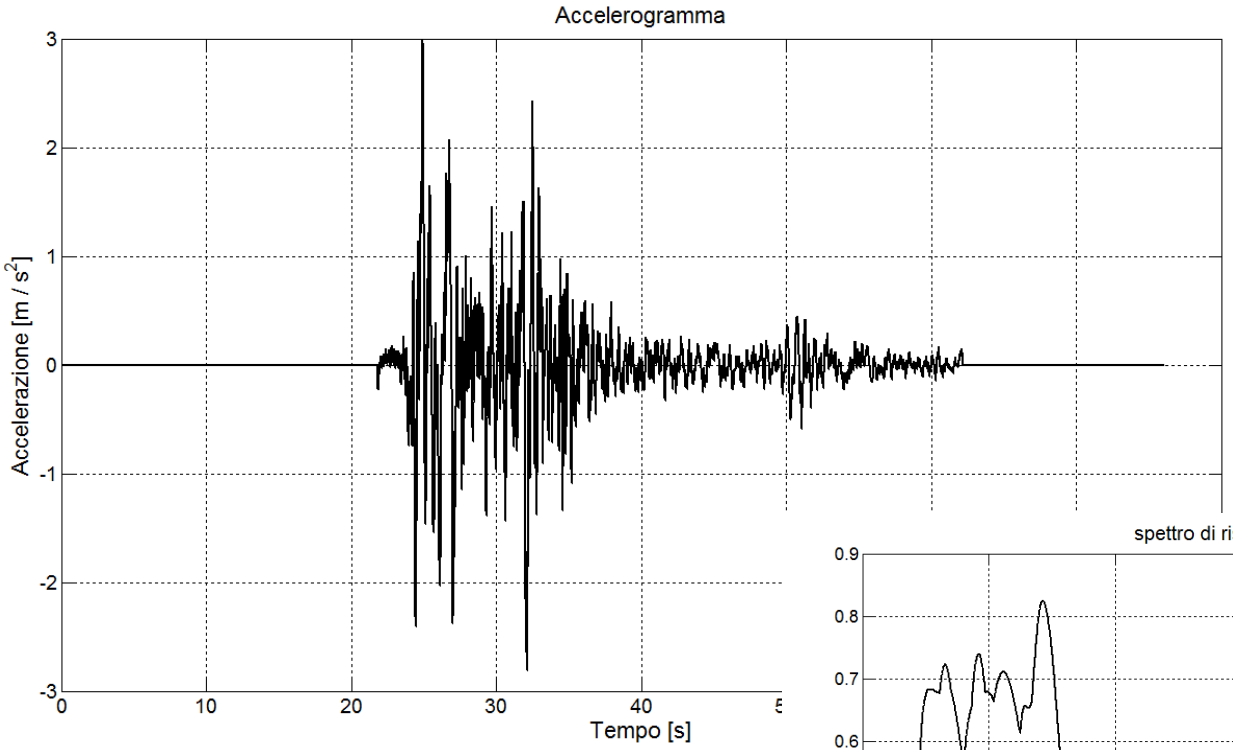


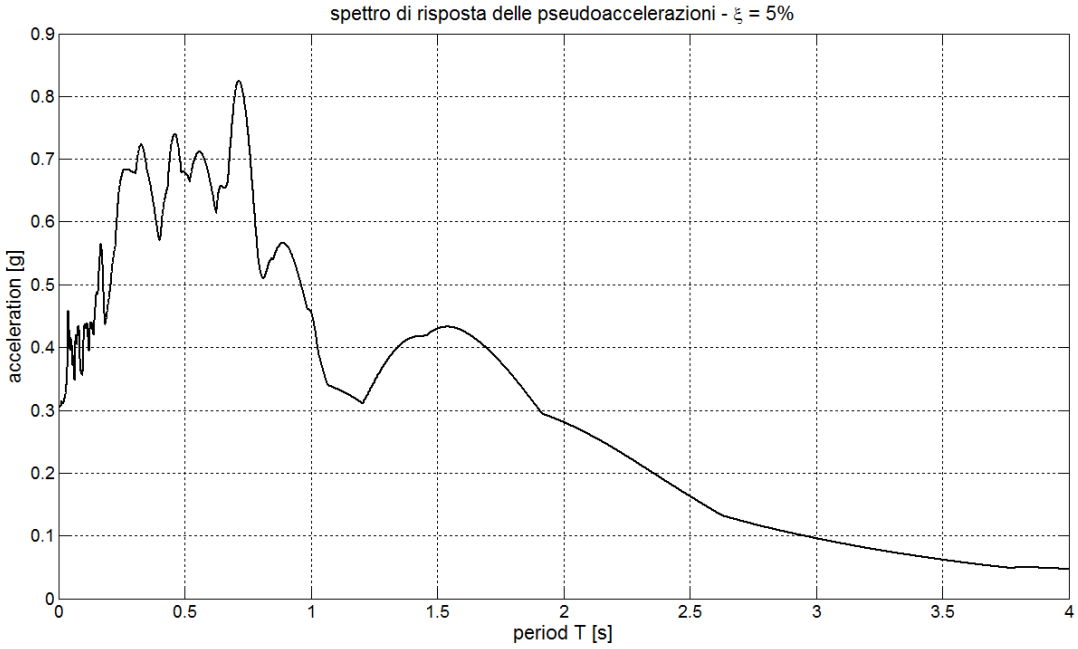


Input

Terremoto del Montenegro (1979)

PGA = 0.305g





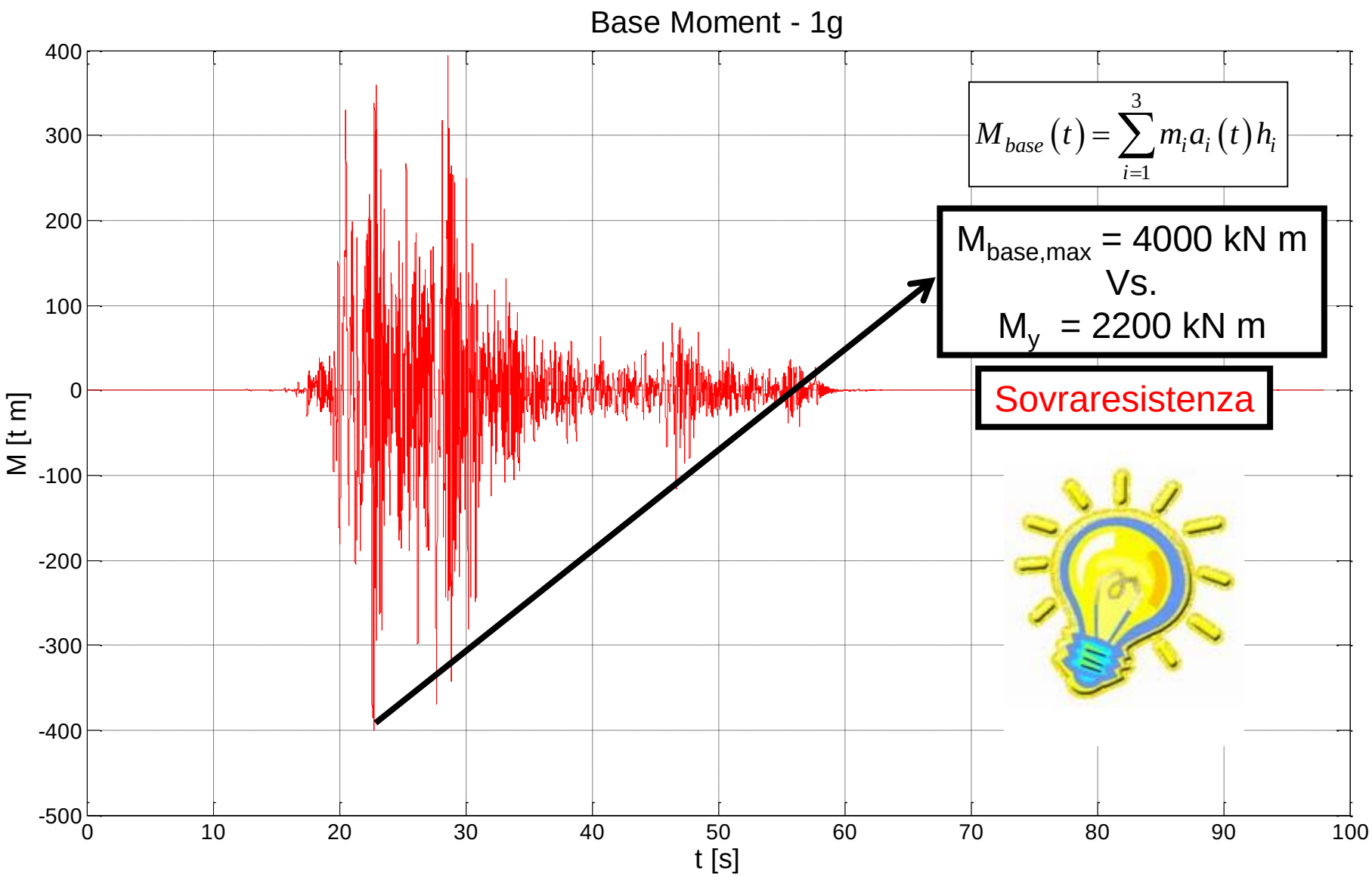
Programma di prova

n.	Nome test	Test
1	T0.05g	Test a 0.05 g
2	T0.15g	Test a 0.15 g
3	T0.50g	Test a 0.50 g
4	T1.00g	Test a 1.00 g
5	T1.20g	1° test a 1.20 g
6	T1.20g	2° test a 1.20 g

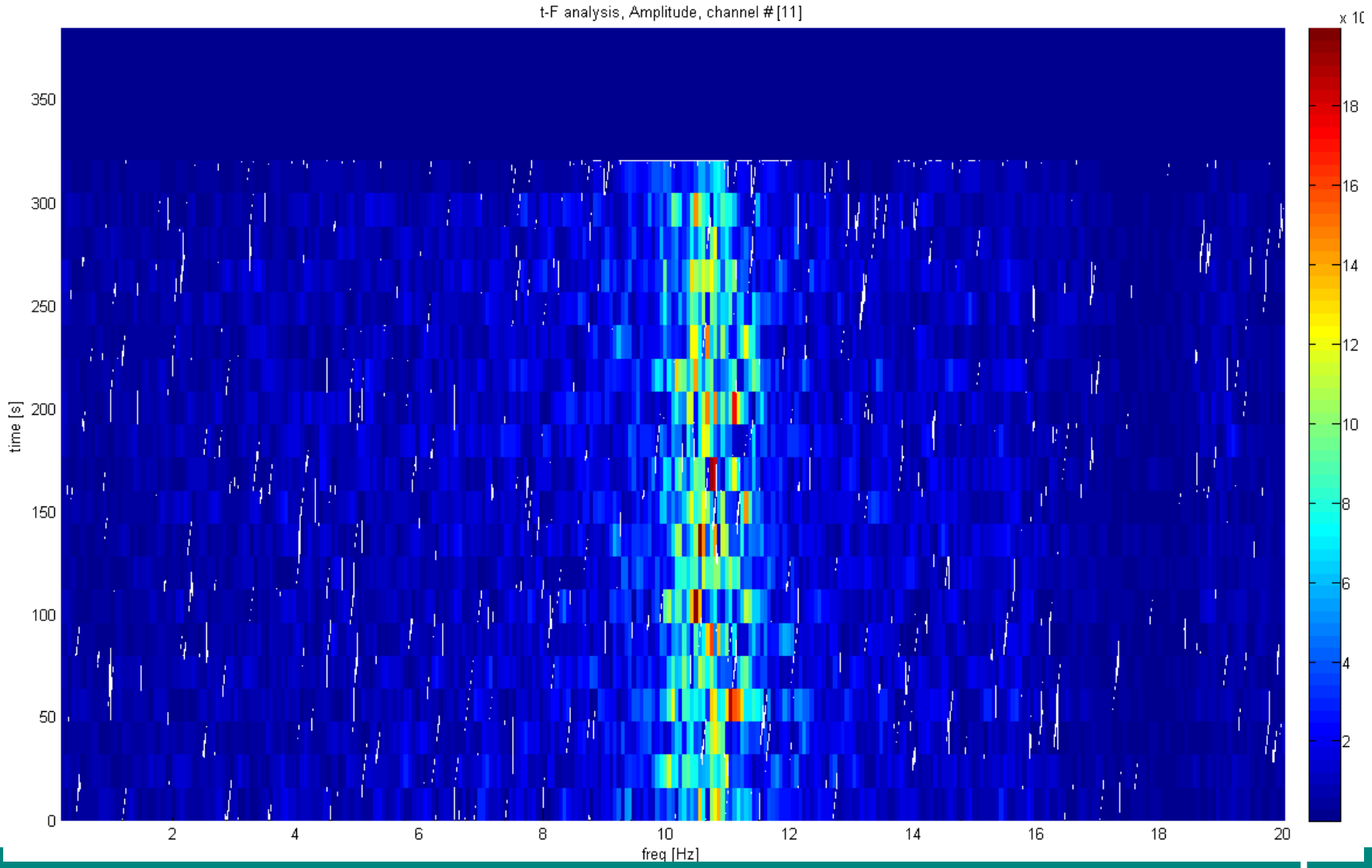
white noise a 0.3g (WN0.3g)

Tra un test e l'altro: **importanti sessioni di white noise**.

Base moment as function of time



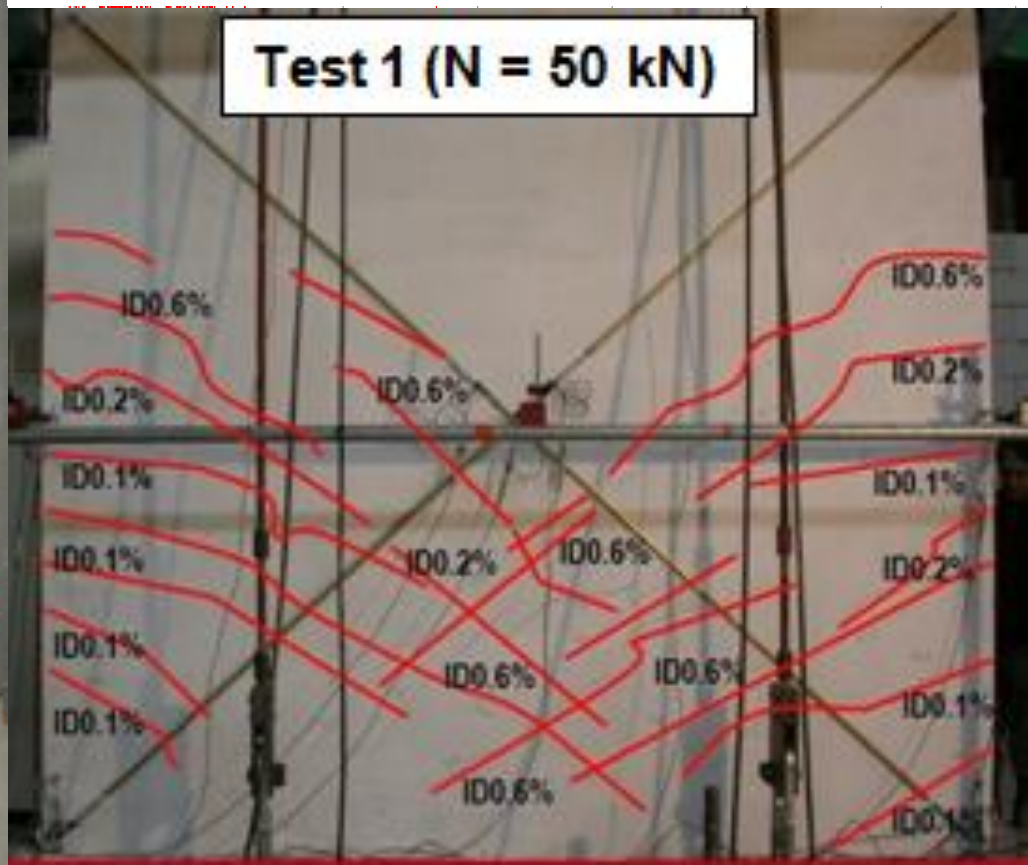
Periodi - Frequenze



Conclusioni (2/2)

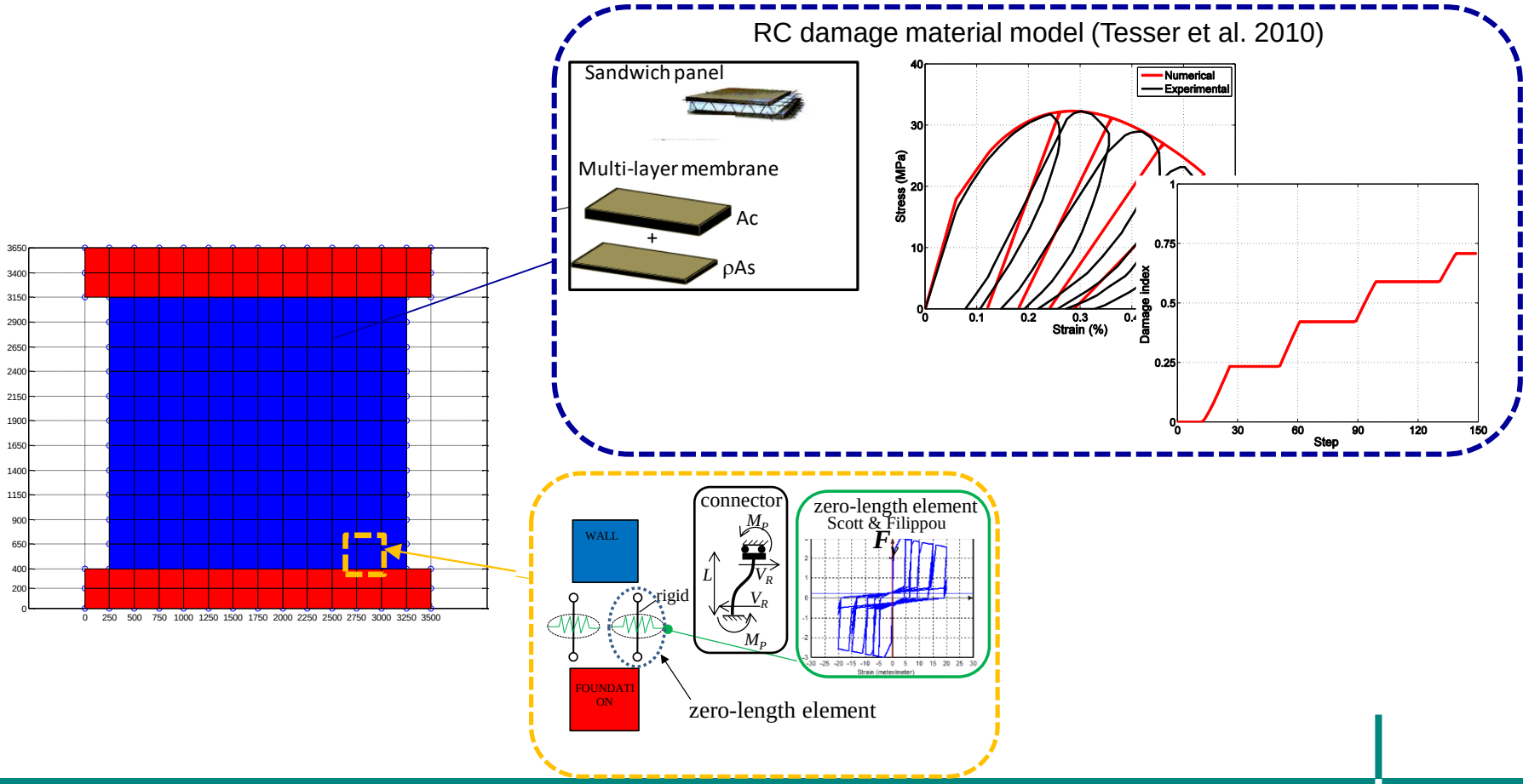
Prova dinamica

Prova pseudo-statica ciclica



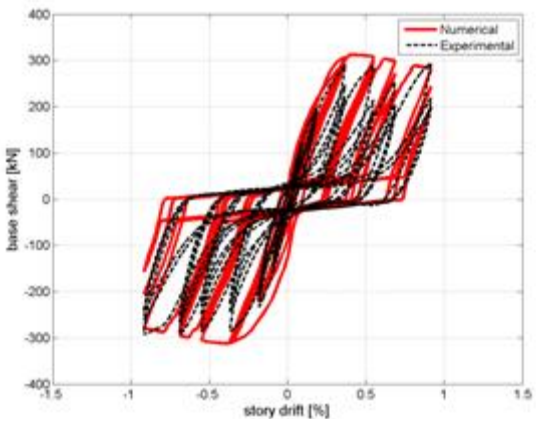
An insight into the post-elastic behavior

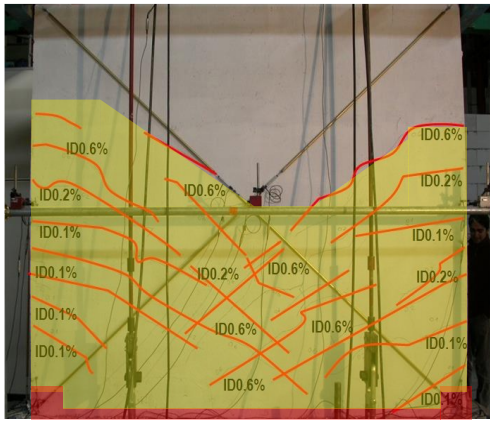
The non-linear numerical model (OPENSEES) able to capture the damage progression

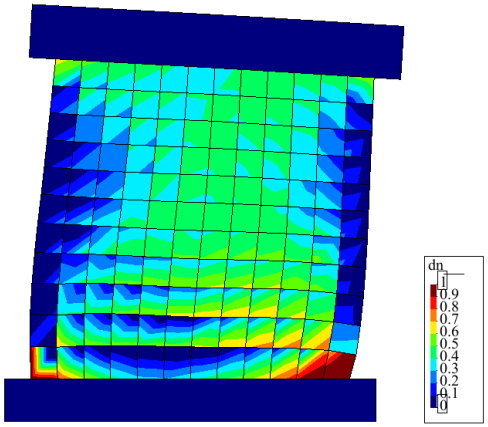


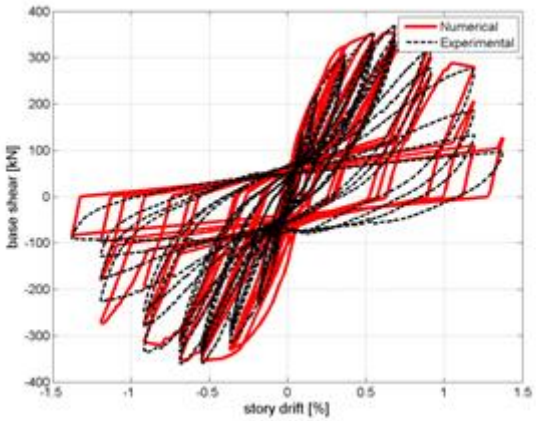
Model validation

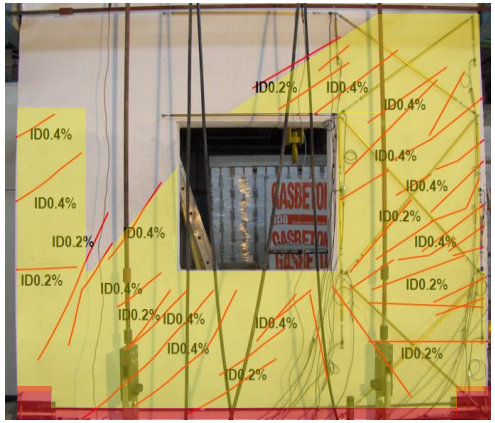
The model well captures the fundamentals of the experimental force-displacement response and damage progression

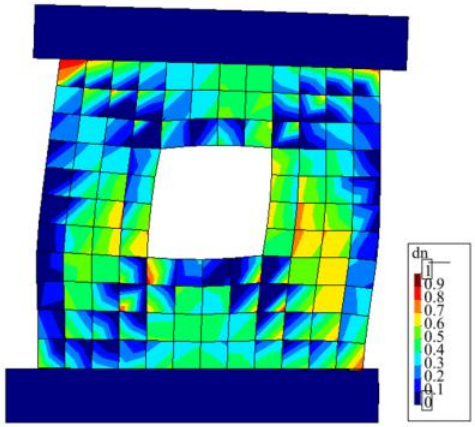












Force-displacement

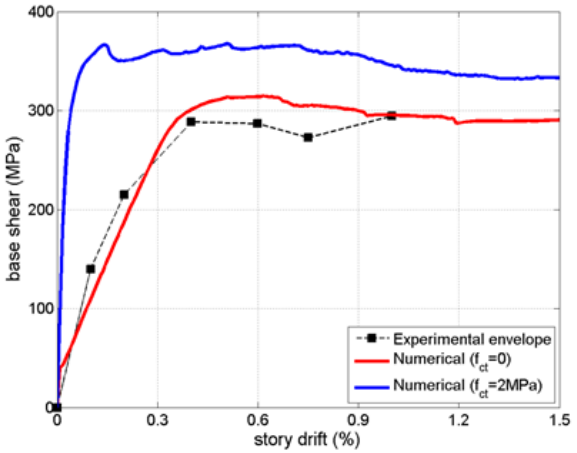
Cracking patterns

Damage maps

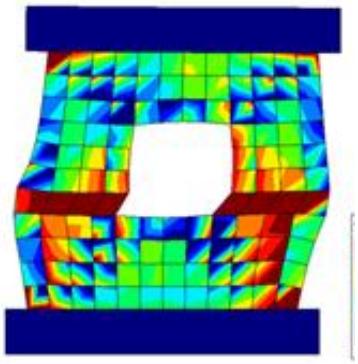
The findings from the numerical-experimental correlation

- Large ductility is due to the presence of smeared steel mesh grid of reinforcement

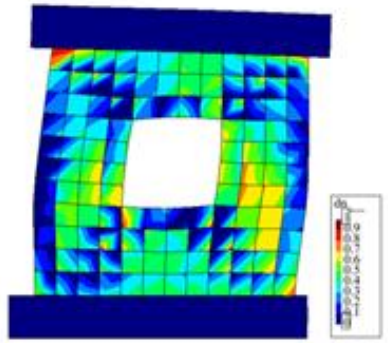
- Controlled damage due to the presence of hysteretic connectors at the base



100% Safety against earthquake



w connectors

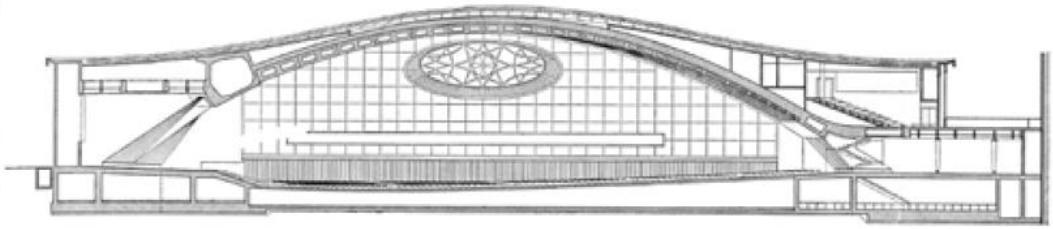


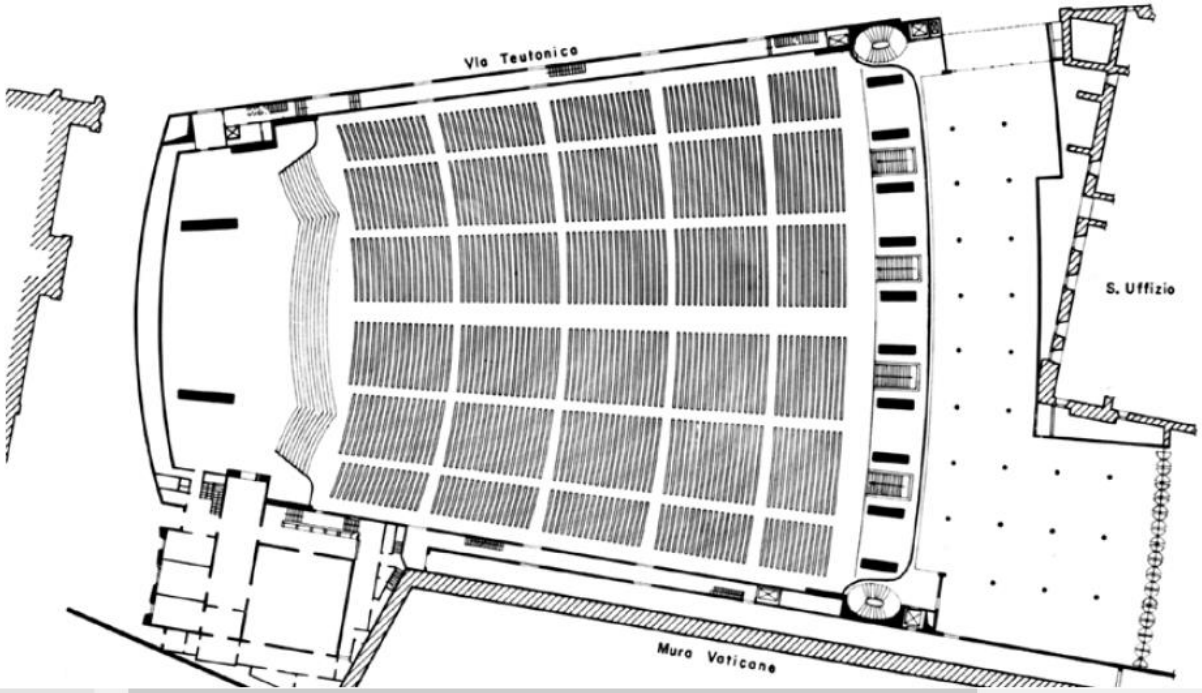
wo connectors

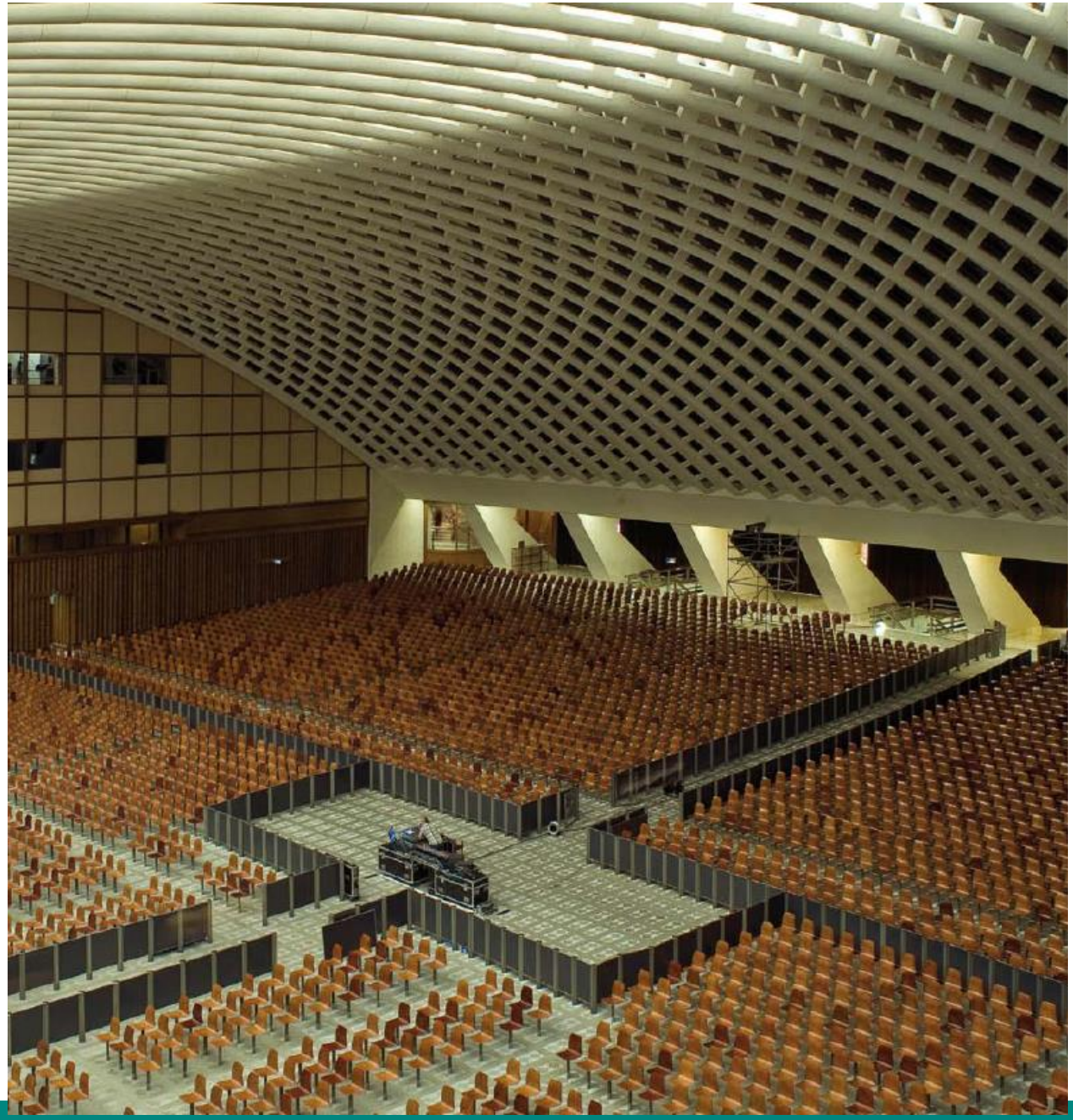
History of engineering

- We need to know where we come from, otherwise we are just collector of formulas
- Engineering is knowledge base invention to control forces of nature

Walter de Maria: Lightening Field




Via Teutonica
S. Uffizio
Mura Vaticane

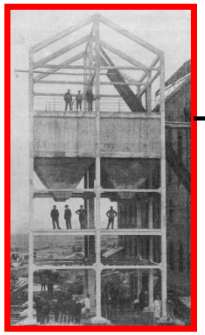


Conclusions

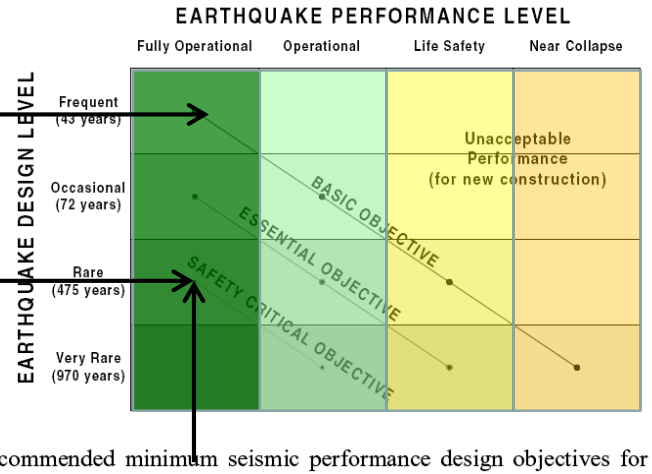
For common buildings up 3-4 (such as schools) it is a **moral duty** to switch to concrete walls (instead of framed structures) for:

- No damage for the design (rare or very rare) earthquake
- Sufficient ductility to guarantee 100% safety for eventual occurrence of larger earthquakes
- Reduced construction costs

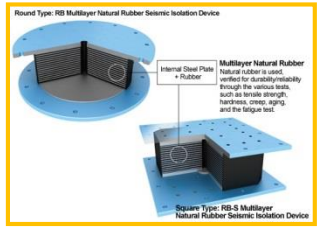
Traditional frame systems: not 100 % safe

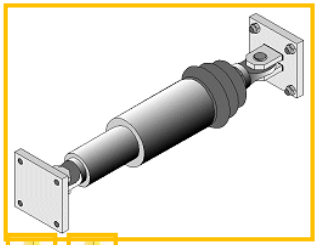


Wall systems: 100 % safe and with reduced costs



Recommended minimum seismic performance design objectives for buildings





Innovative solutions (e.g. isolation): 100 % safe, but expensive