

REMTECH EXPO

GEOSISMICA

L'isolamento sismico per edifici nuovi e per l'adeguamento di edifici esistenti

Elena Mele



Università degli Studi di Napoli Federico II

Dipartimento di Strutture per l'Ingegneria e l'Architettura

Tecnologie innovative di mitigazione del rischio sismico per edifici strategici, serbatoi, sili e torrini

20 settembre 2019

RemTech Expo 2019 (18, 19, 20 Settembre) FerraraFiere

www.remtechexpo.com

progettazione sismica

fine

preservare vita umana
prevenire collasso



mezzo

danneggiamento, anche severo,
controllato



Loma Prieta: \$ 7 Mld \$0.5 Mld/sec

Northridge: \$ 80 Mld \$2 Mld/sec

Kobe: \$ 190 Mld \$7.5 Mld/sec

Tohoku: \$ 324 Mld → 3-4% Japan's annual GDP

edilizia esistente - Italia



impatto economico

Terremoto	M€ (attualizzato)	Periodo
Belice 1968	8375	1968-2018
Friuli 1976	16917	1976-2006
Irpinia 1980	47470	1980-2023
Umbria-Marche 1997	12284	1997-2024
S. Giuliano 2002	1300	2002-2023
Abruzzo 2009	17458	2009-2047
Emilia 2012	8171	2012-2047
Italia centrale 2016	13163	2016-2047

periodo 1969-2002 dati da:
Dossier Camera 14/5/2009

periodo 2009-oggi dati da:
report del Senato

valori ricalcolati rispetto al valore
attuale in euro

ad esclusione terremoto Friuli 1976,
per tutti gli altri eventi il periodo di
impegno finanziario è ancora
pienamente attivo

**costo attualizzato dei terremoti principali in Italia degli ultimi 50 anni
tot. > 125 miliardi di euro**

considerando tutti i terremoti in 50 anni: 150 -160 miliardi di euro

sostenibilità

il danneggiamento sismico si traduce in impatto sociale, economico e culturale di lunga durata sulle comunità e città

sostenibilità : ridurre gli impatti di eventi anomali come i terremoti minimizzando la necessità di riparazioni e interruzioni del servizio

sostenibilità = resilienza

beyond safety: issues for sustainable and earthquake-resilient structures

base isolation system (BIS)

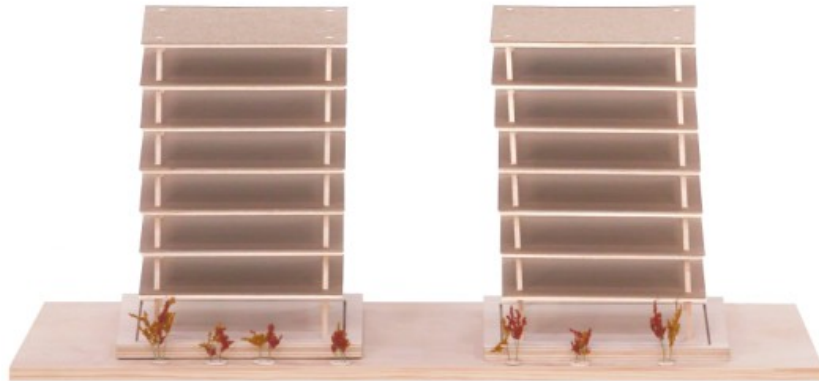
the underlying philosophy of base isolated buildings is to **outperform** fixed base constructions in moderate and large earthquakes

J. M. Kelly

principle of base isolation system (BIS)

superstructure almost rigid

deformation concentrated in isolation layer



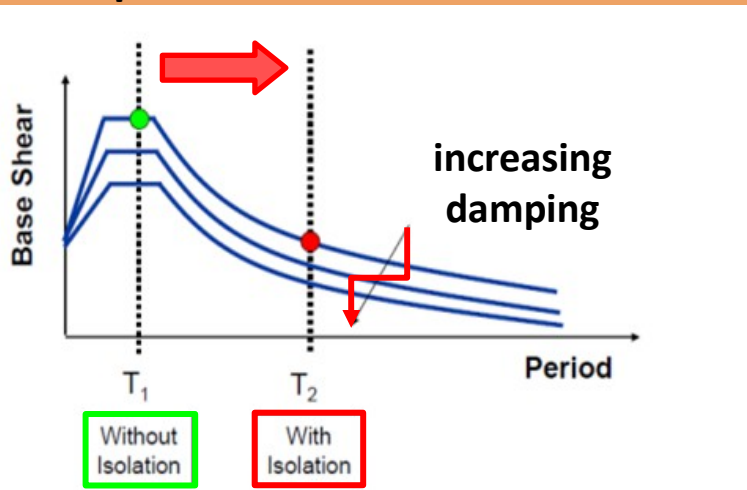
with isolation

without isolation

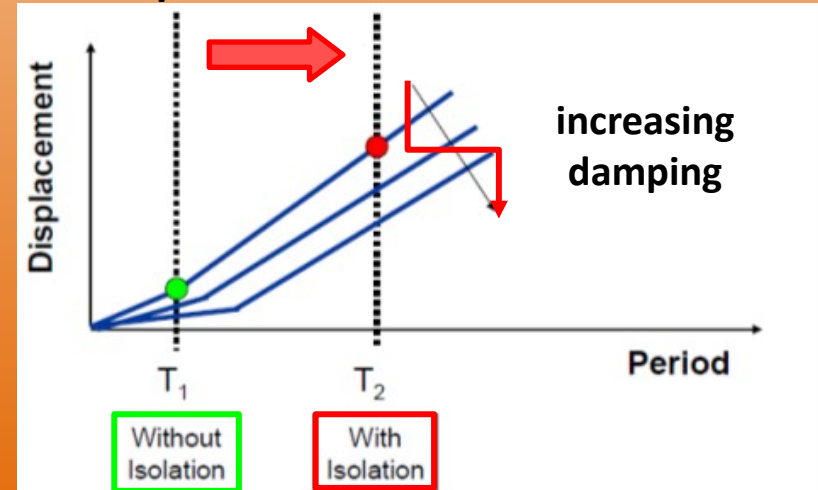
- flexibility to increase period of vibration and reduce seismic demand

- energy dissipation to control isolation displacement

period shift

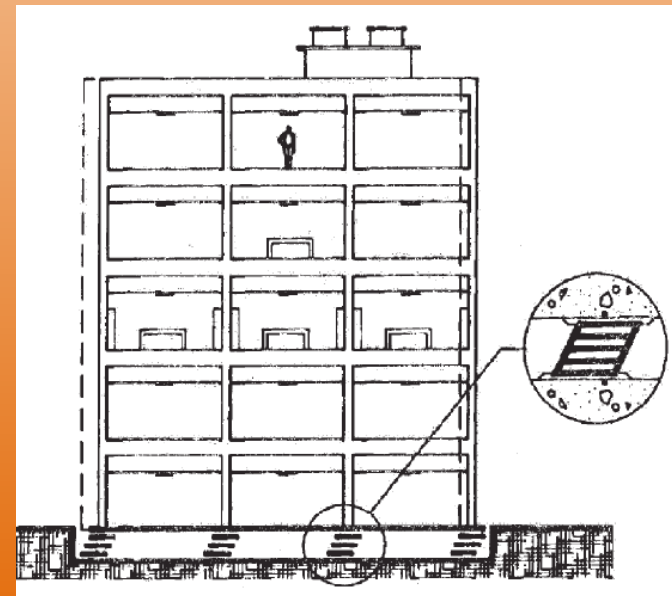


period shift

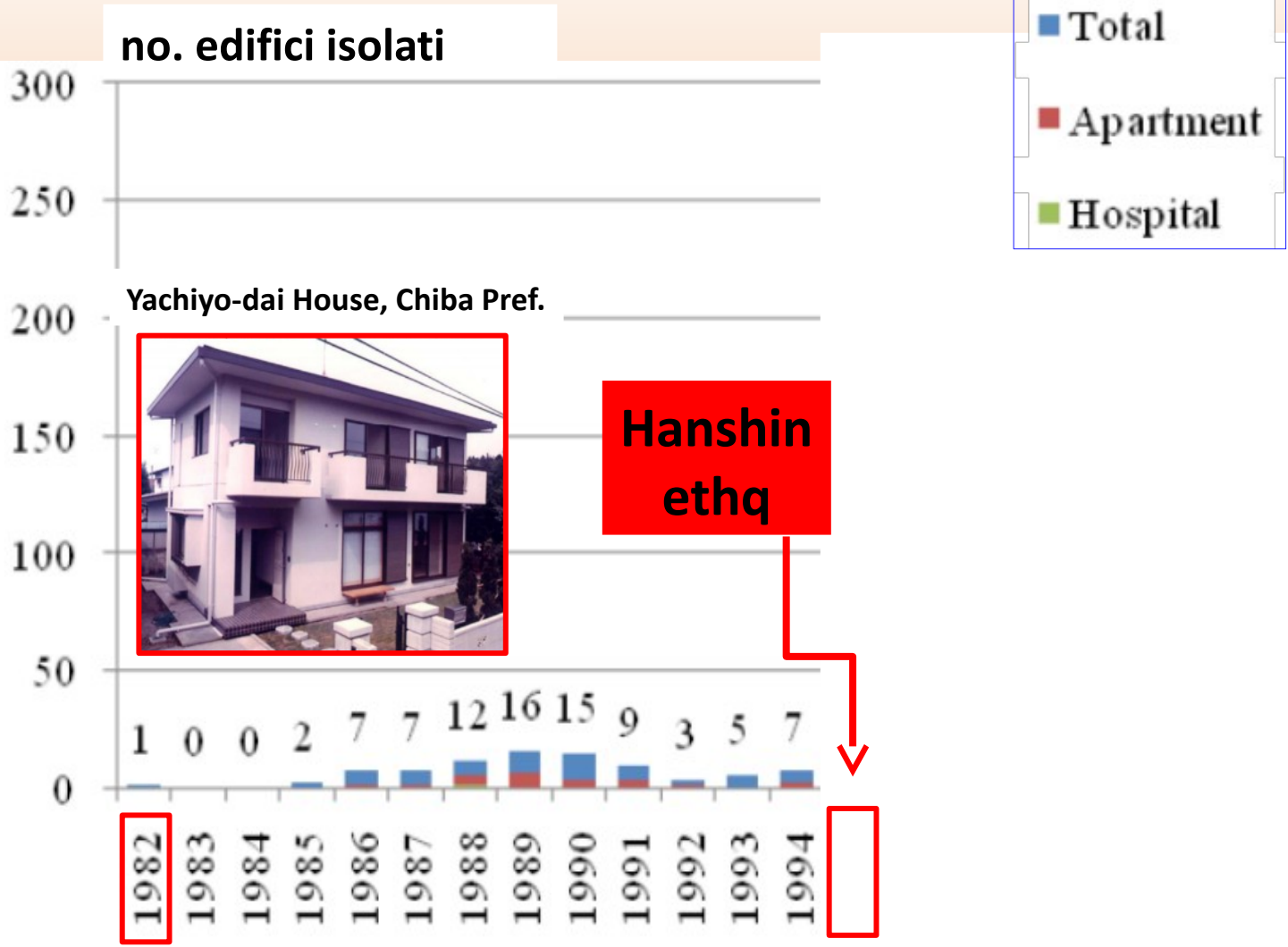


BIS: vantaggi

- comportamento dinamico semplice
- sezioni elementi strutturali minori
- sistema strutturale meno invasivo (progettazione per soli CV)
- **riduzione danni dovuti ad accelerazioni e spostamenti**
- **costi riparazione minori a fronte di costi iniziali leggermente maggiori (5-10%)**



edifici con isolamento sismico in Giappone

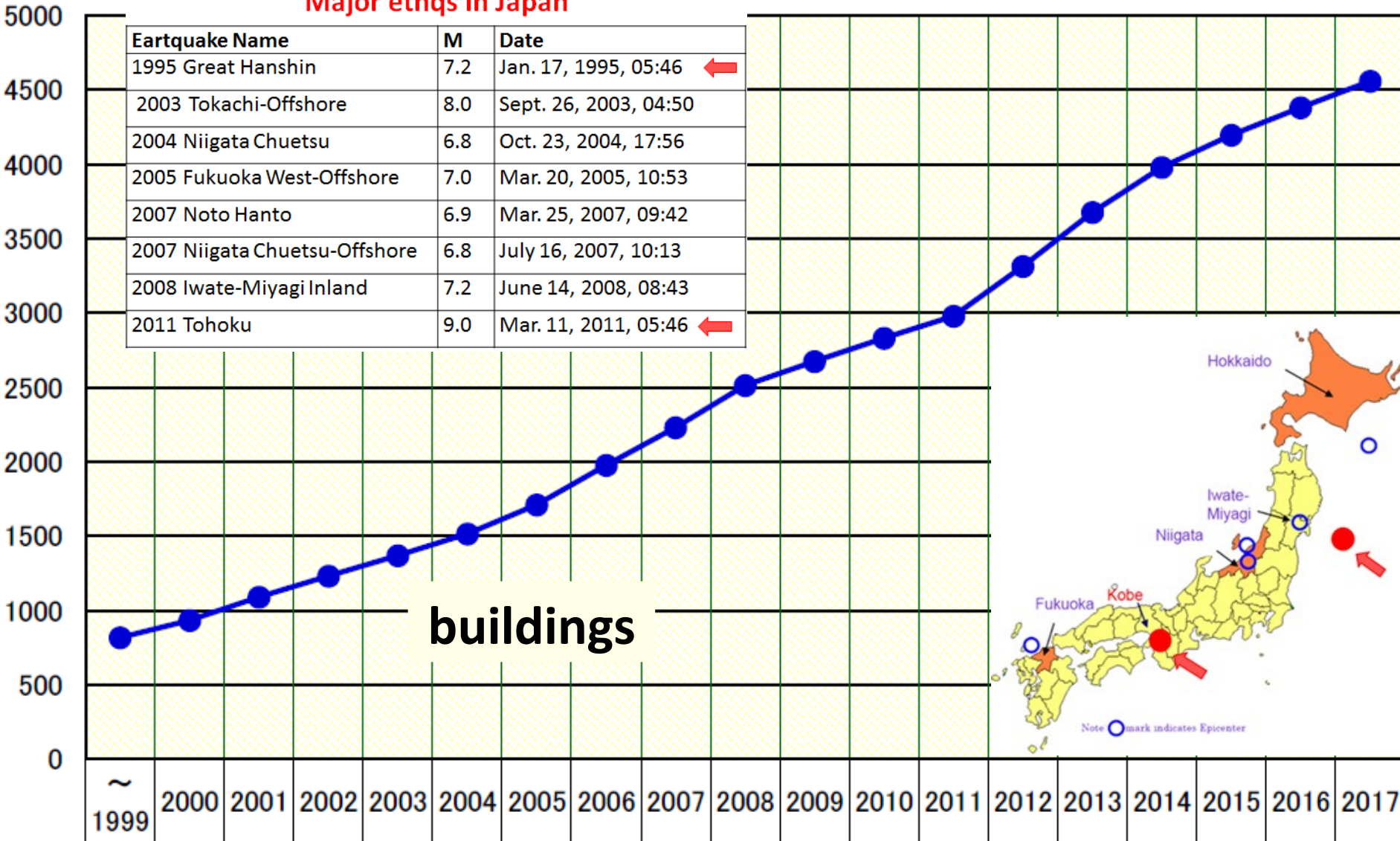


dal 1995: 150-250 edifici all'anno
 al 2017: più di 4500 edifici e 5000 case

edifici con isolamento sismico in Giappone

Major ethqs in Japan

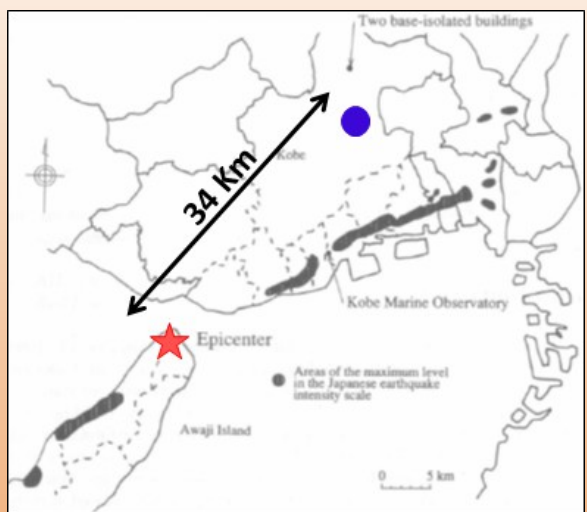
Eartquake Name	M	Date
1995 Great Hanshin	7.2	Jan. 17, 1995, 05:46
2003 Tokachi-Offshore	8.0	Sept. 26, 2003, 04:50
2004 Niigata Chuetsu	6.8	Oct. 23, 2004, 17:56
2005 Fukuoka West-Offshore	7.0	Mar. 20, 2005, 10:53
2007 Noto Hanto	6.9	Mar. 25, 2007, 09:42
2007 Niigata Chuetsu-Offshore	6.8	July 16, 2007, 10:13
2008 Iwate-Miyagi Inland	7.2	June 14, 2008, 08:43
2011 Tohoku	9.0	Mar. 11, 2011, 05:46



tot.	817	933	1090	1231	1370	1514	1710	1977	2230	2513	2673	2830	2978	3312	3676	3978	4194	4380	4557
-------------	-----	-----	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------	------

major earthquakes in Japan and performance of BIS

The 1995 Great Hanshin Earthquake, M=7.2

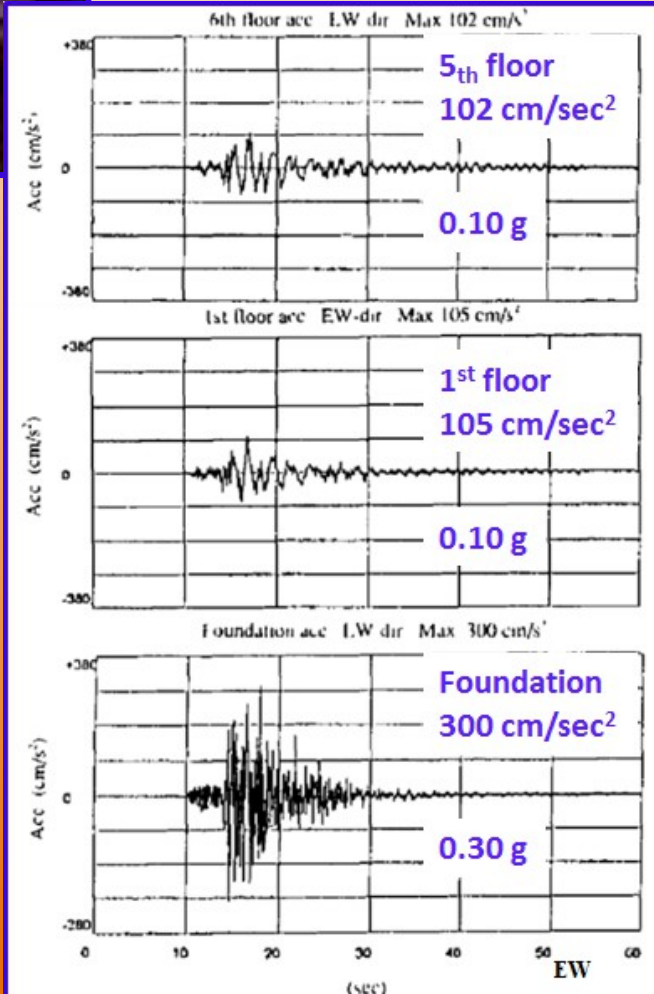
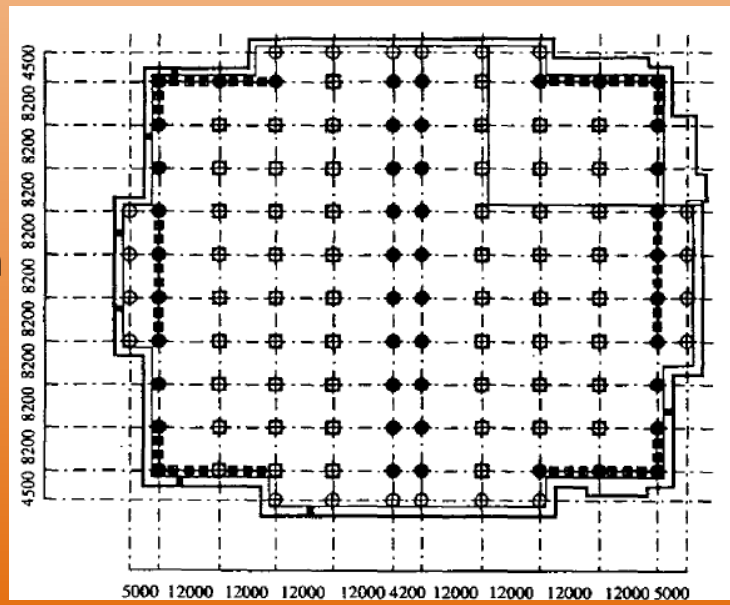


Computer Center MPT, Kobe
 area = 8563 m²
 H= 38 m, 6 stories
 SRC structure

AMR=PRA/PGA = 0.34

- 120 SI
- 54 LRBs Φ 1200mm
- 46 RBs Φ 1000mm
- 20 RBs Φ 800mm

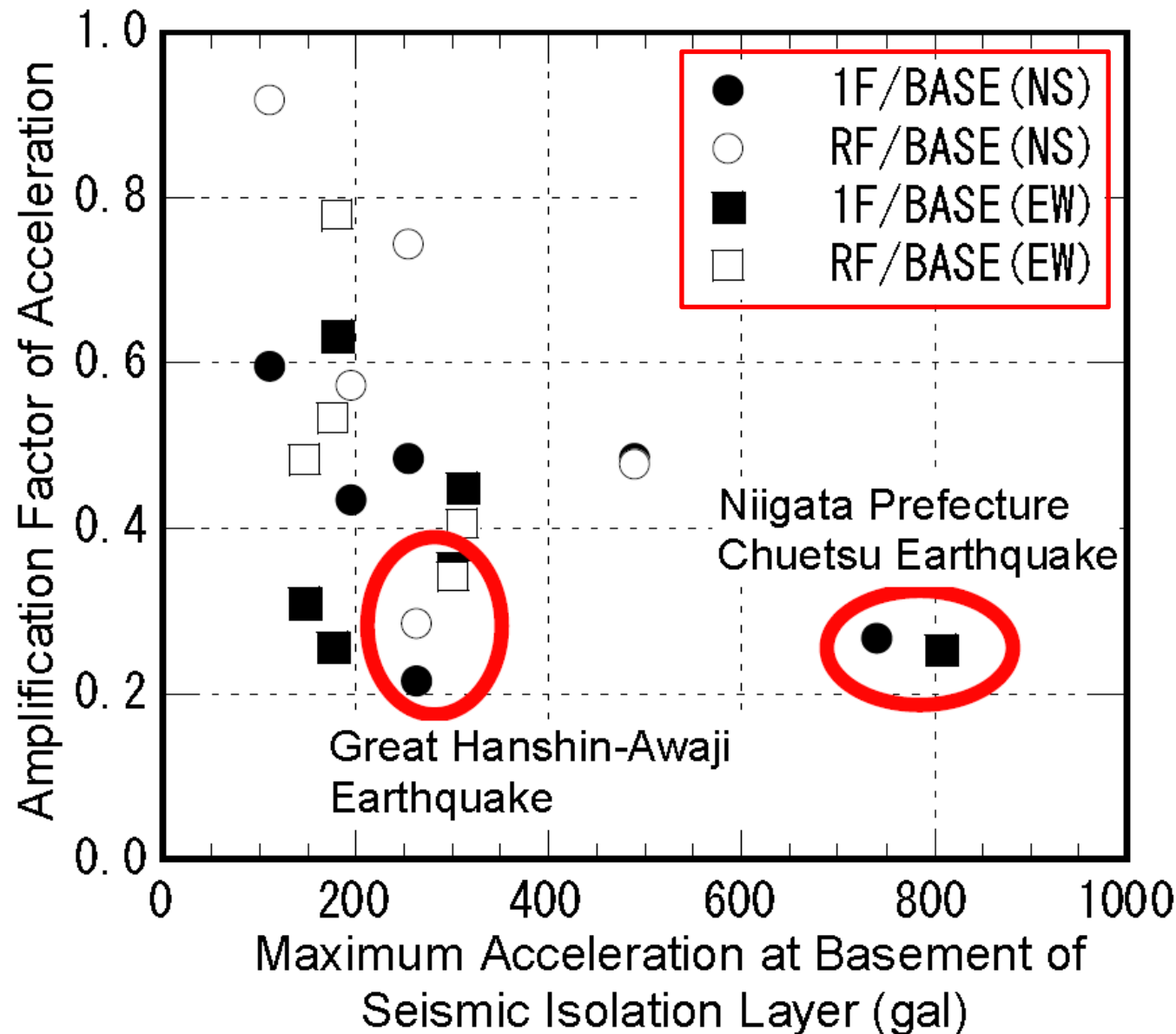
- 44 Steel Dampers
- Φ 70mm



acceleration magnification ratio

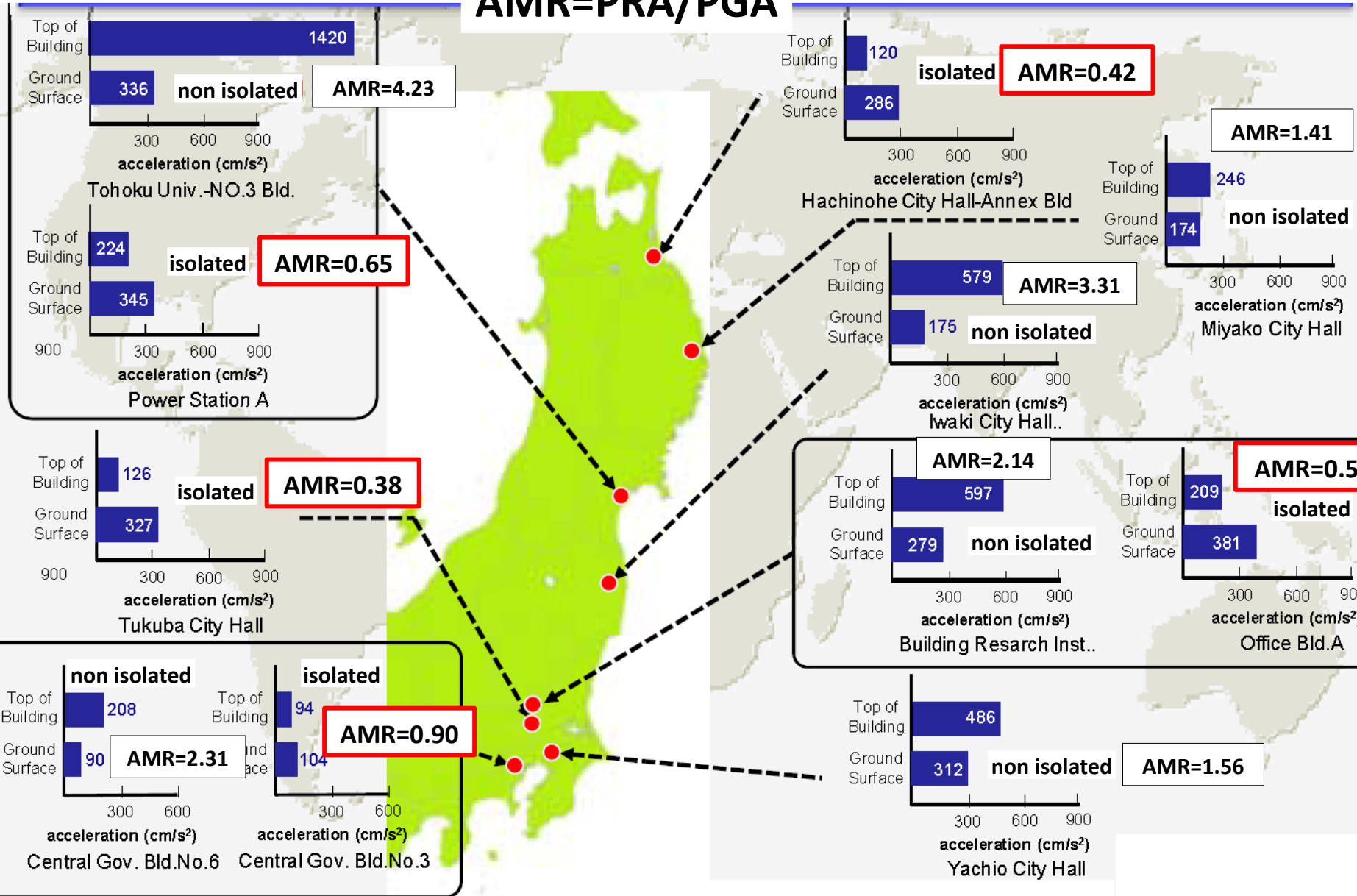
The 1995 Great Hanshin Earthquake, M=7.2

2007 Niigata Chuetsu-Offshore Earthquake, M=6.8

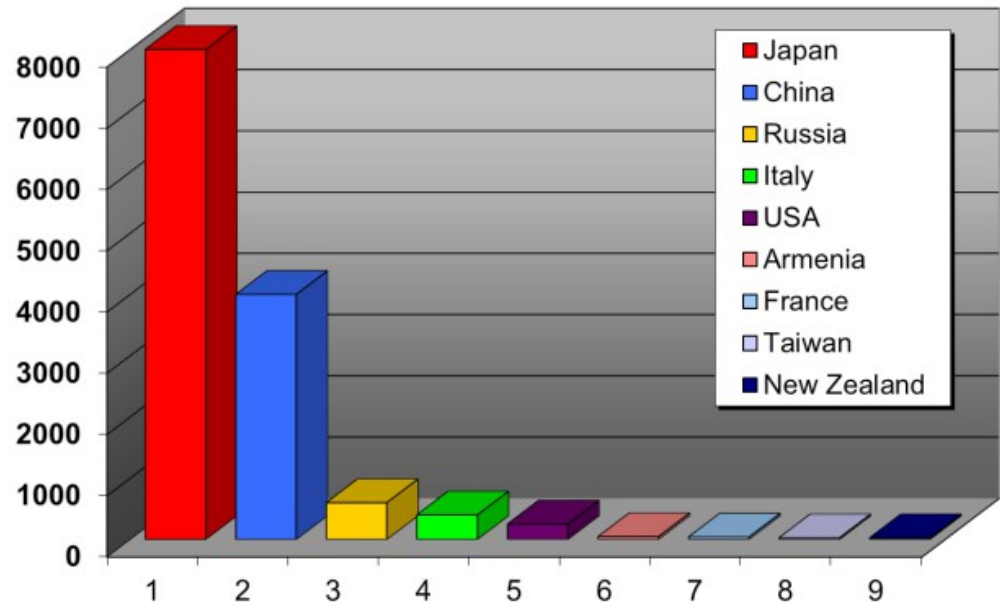


2011 Tohoku Earthquake, M=9.0 - Records of SI Bldgs in East Japan

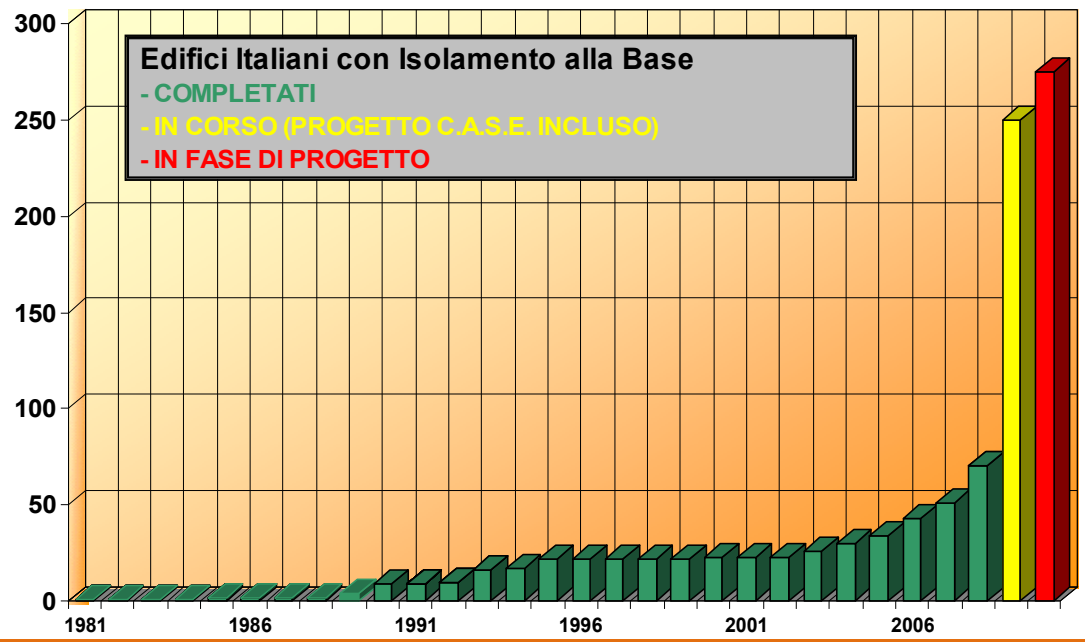
AMR=PRA/PGA



edifici con isolamento sismico nel mondo e Italia



No. edifici isolati nel mondo (al 2013)



No. edifici isolati in Italia (al 2009)

il BIS per edifici di nuova costruzione

Progetto C. A. S. E. – L'Aquila



185 edifici
(36 acciaio, 82 legno, 57
cls)
7368 isolatori

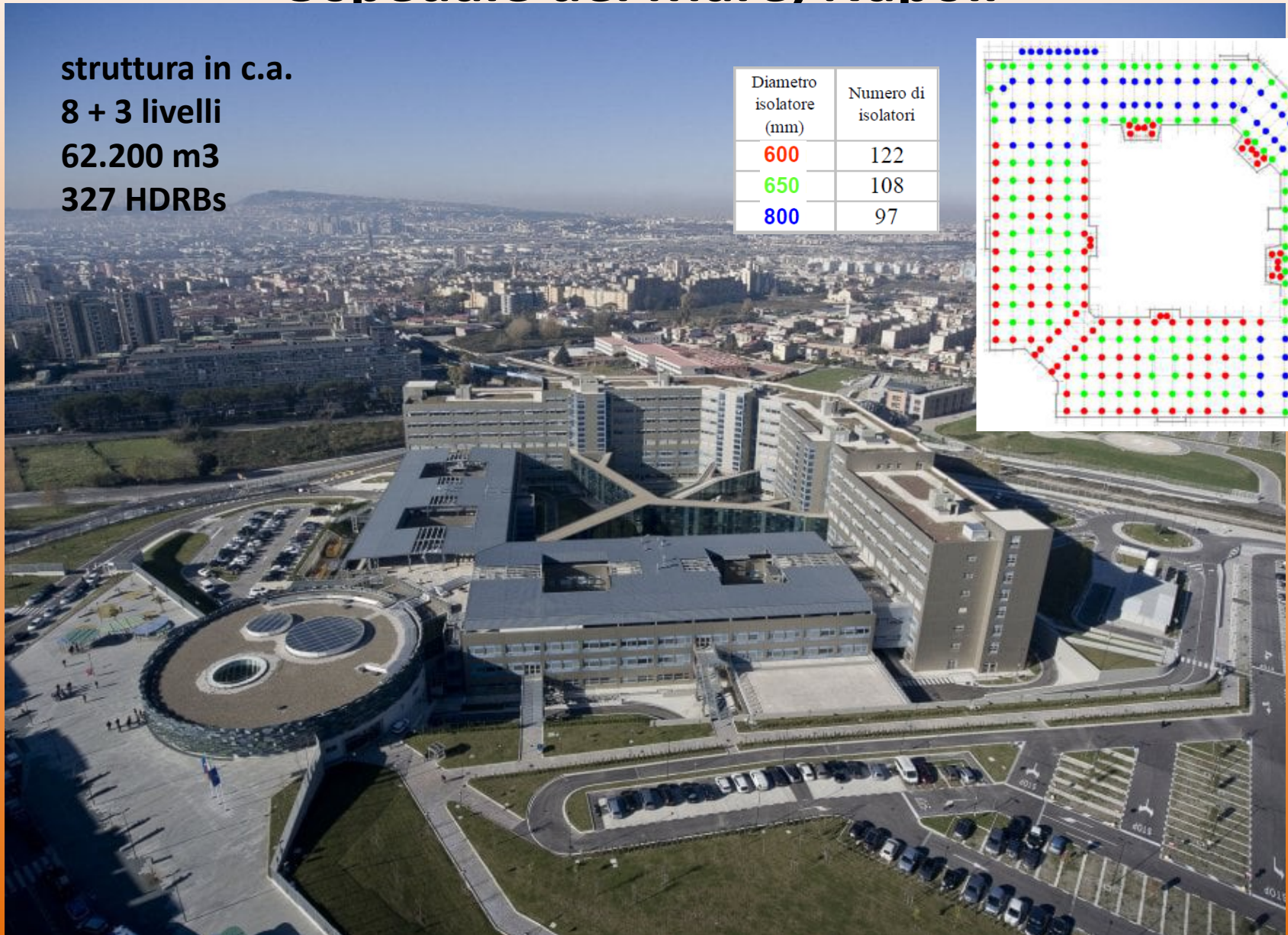
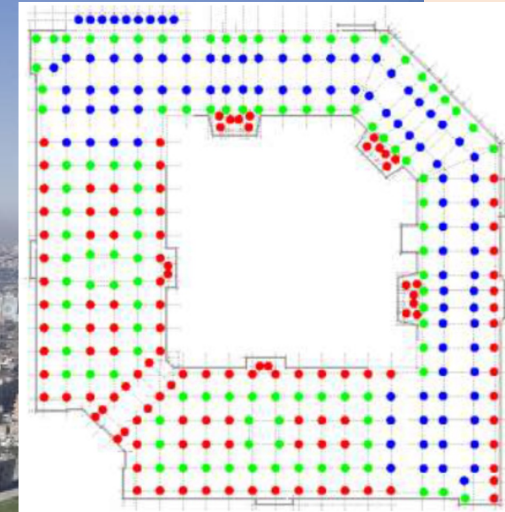
- Abitazioni e quartieri disponibili in cinque/sei mesi
- Sicurezza antisismica di “isolato urbano”
- Elevato livello dello standard abitativo
- Elevato livello tecnologico orientato all’autosufficienza impiantistica
- Sostenibilità ambientale e bioedilizia

il BIS per edifici strategici

Ospedale del Mare, Napoli

struttura in c.a.
8 + 3 livelli
62.200 m³
327 HDRBs

Diametro isolatore (mm)	Numero di isolatori
600	122
650	108
800	97



il BIS per adeguamento sismico di edifici strategici il Centro Polifunzionale di Soccavo, Napoli

struttura in c.a. prog. solo CV (1979)

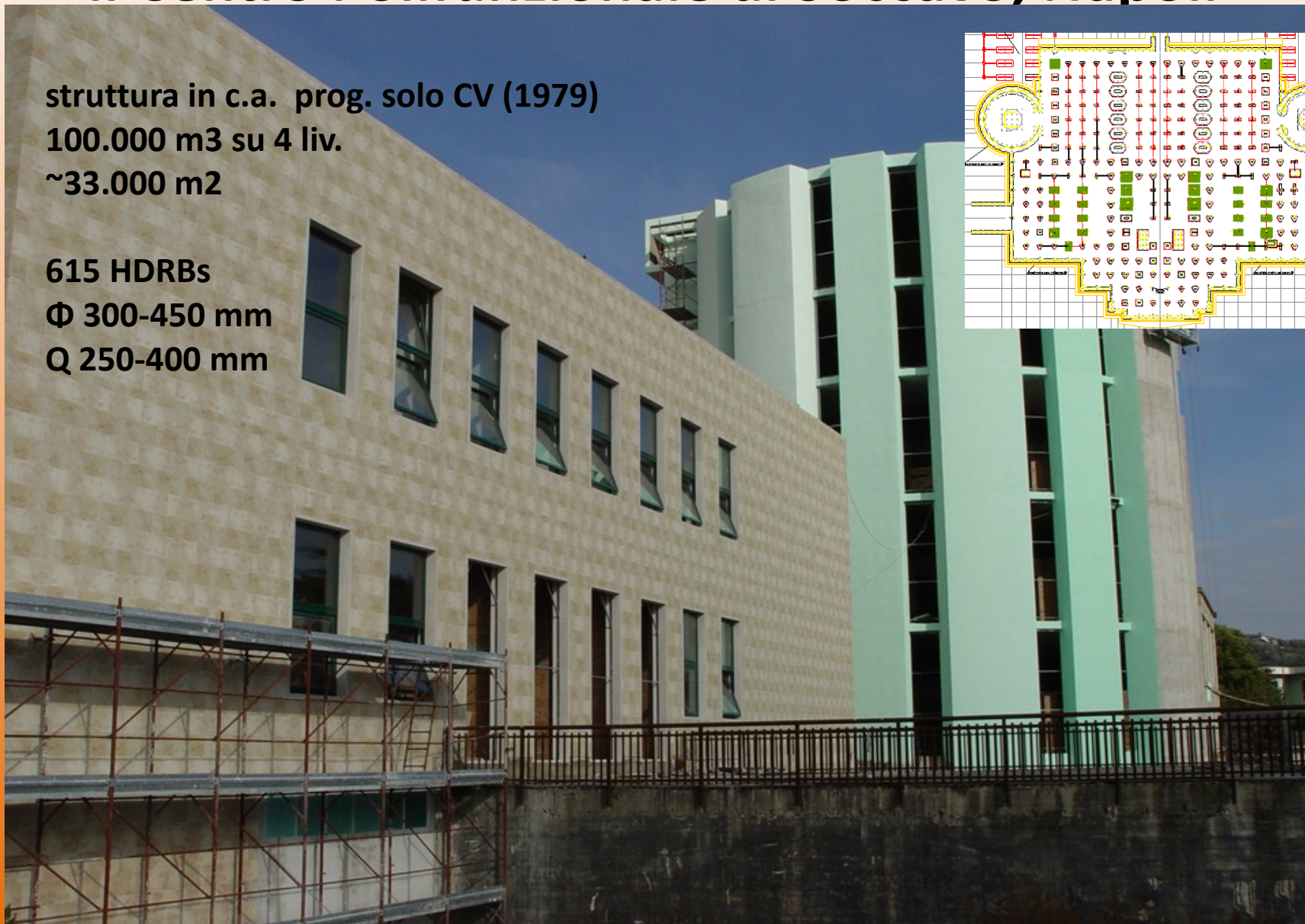
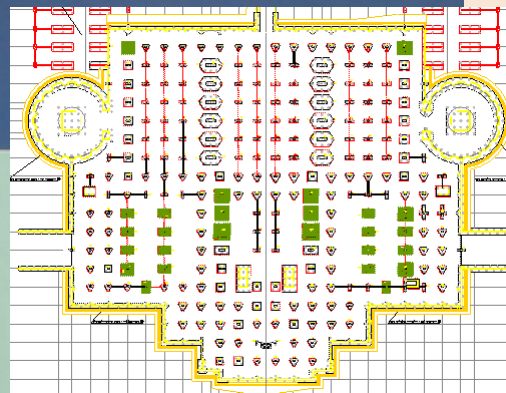
100.000 m³ su 4 liv.

~33.000 m²

615 HDRBs

Φ 300-450 mm

Q 250-400 mm



expanded scope of application and new design trends (Jap)

- high-rise buildings (250 bldgs, most r.c. condominiums, most in Tokyo)
- complex shapes and long span
- lightweight structures
- retrofit of existing buildings (monuments; ordinary)

landmark works
of architecture

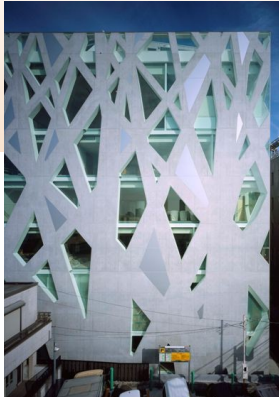
- **mid-story** isolation
- **roof/top** storeys isolation
- **ground** isolation

acting
as TMD

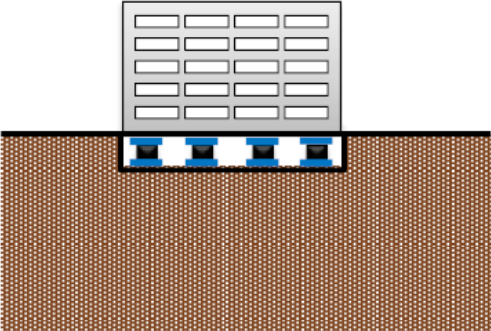
both new bldgs
and retrofit

isolamento sismico: nuove tendenze

aesthetic

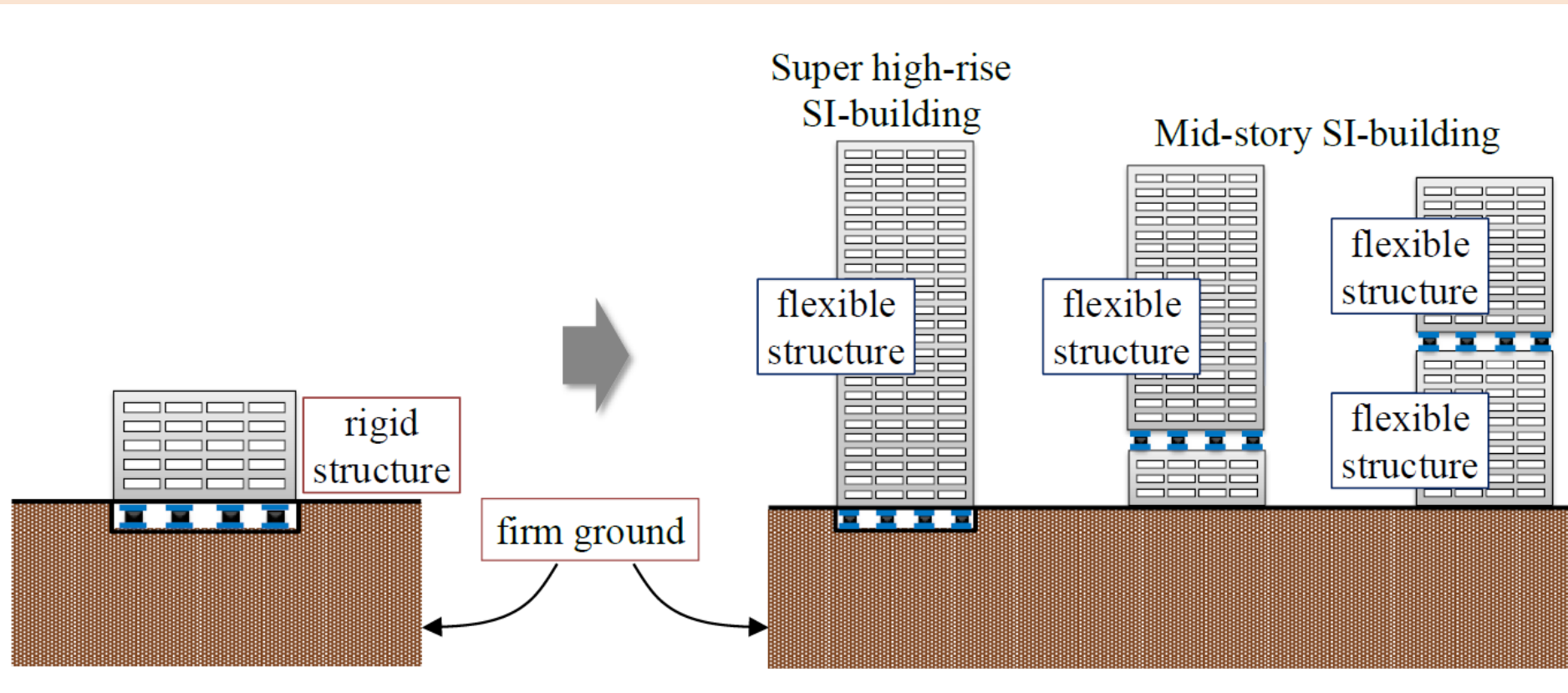


utilitarian



utilitarian to aesthetic → BIS applications enabling elegant aesthetics in landmark works of architecture not otherwise be possible in strong seismic regions

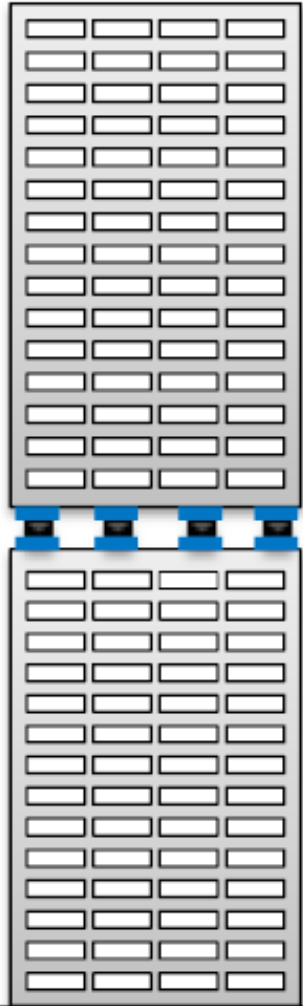
isolamento sismico: nuove tendenze



ieri : isolamento alla base, struttura rigida

oggi : isolamento alla base di edifici alti, isolamento a livelli intermedi, gran varietà di soluzioni

isolamento sismico intermedio (IIS)



US

sistema ad isolamento sismico intermedio: lo strato di isolamento è ubicato lungo l'altezza dell'edificio

si individuano così:

- sottostruttura (LS)
- sovrastruttura (US)

LS

vantaggi

- fattibile dove il BIS è morfologicamente impraticabile (es. aree densamente urbanizzate)
- non necessita di alcun gap attorno all'isolamento
- applicabile anche in edifici alti
- massima libertà architettonica (LS e US: differenti funzioni e/o sistemi strutturali)
- LS meno sollecitata (effetto MD)

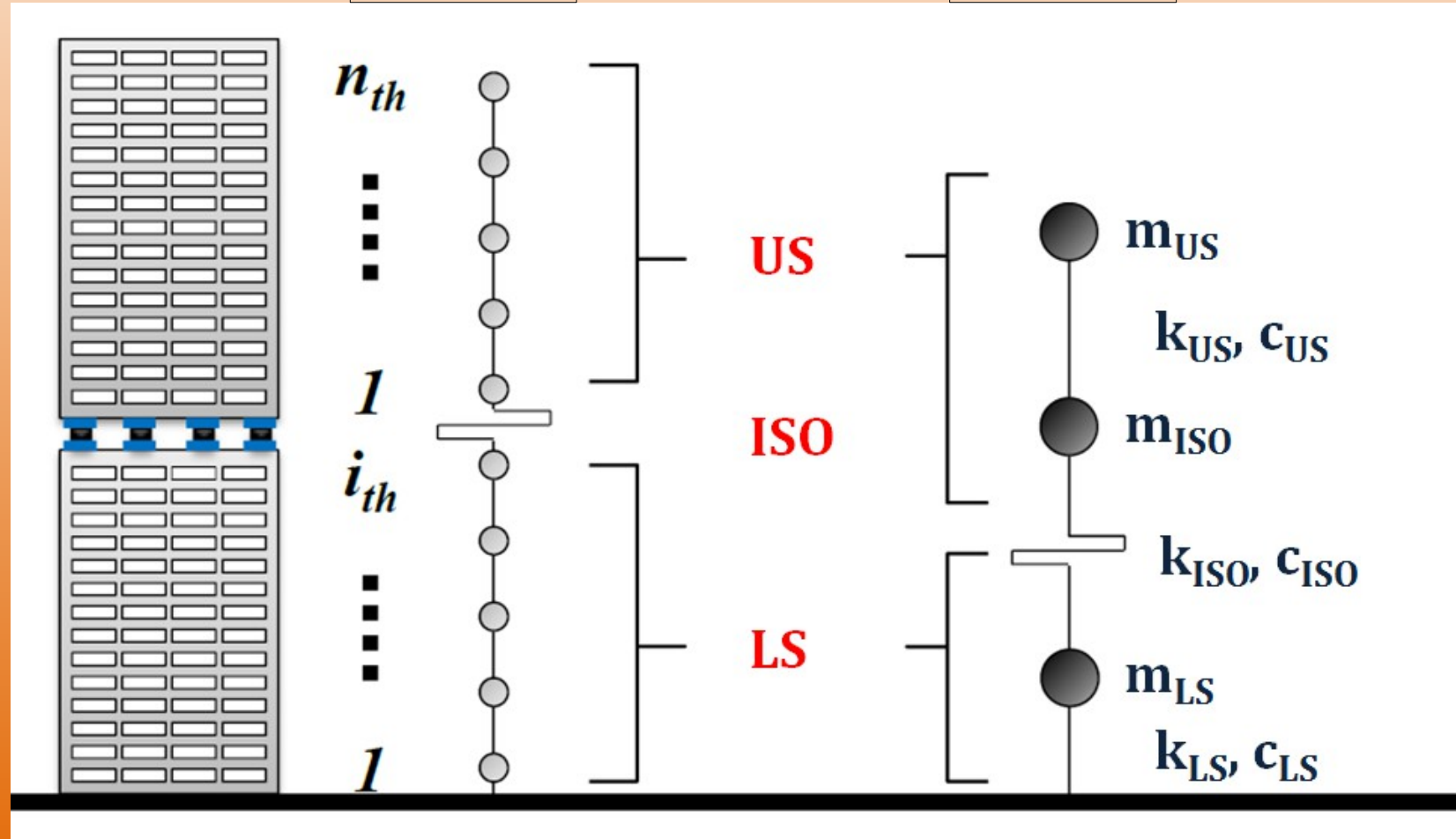
isolamento sismico intermedio (IIS)

edificio

modelli a masse concentrate

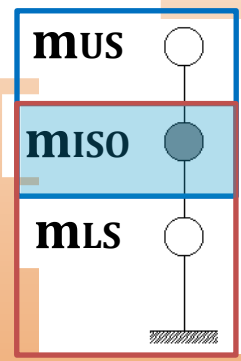
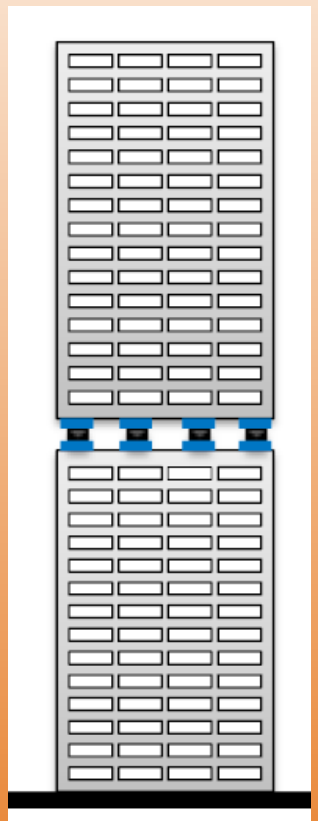
n-DOF

3DOF



isolamento sismico intermedio (IIS)

3DOF IIS



2DOF BIS

$$\begin{cases} m_{US}\ddot{u}_{US} + c_{US}\dot{v}_{US} + k_{US}v_{US} = 0 \\ m_{ISO}\ddot{u}_{ISO} + c_{ISO}\dot{v}_{ISO} + k_{ISO}v_{ISO} = 0 \\ m_{LS}\ddot{u}_{LS} + c_{LS}\dot{v}_{LS} + k_{LS}v_{LS} = \underbrace{c_{ISO}\dot{v}_{ISO} + k_{ISO}v_{ISO}}_{m_{ISO}\ddot{u}_{ISO} = -f} \end{cases}$$

SDOF TMD

$$m_{ISO}\ddot{u}_{ISO} = -f$$

the 2nd dof is an IS for US and a MD for the LS

IIS negli edifici alti

Nakanoshima Festival Tower, Osaka (JAP)

H = 200 m, No.st. 39

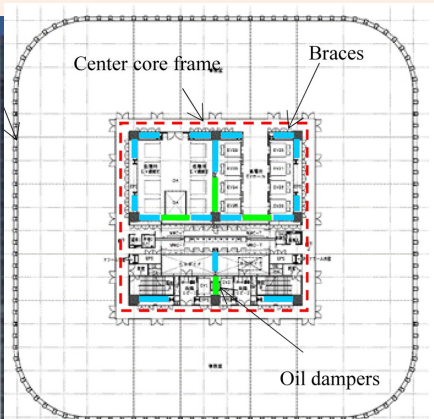
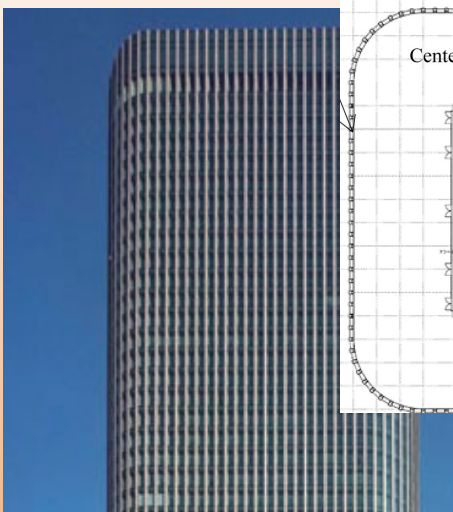


uffici

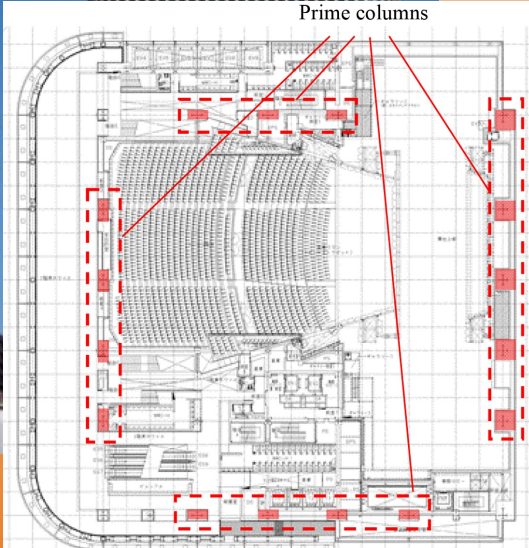
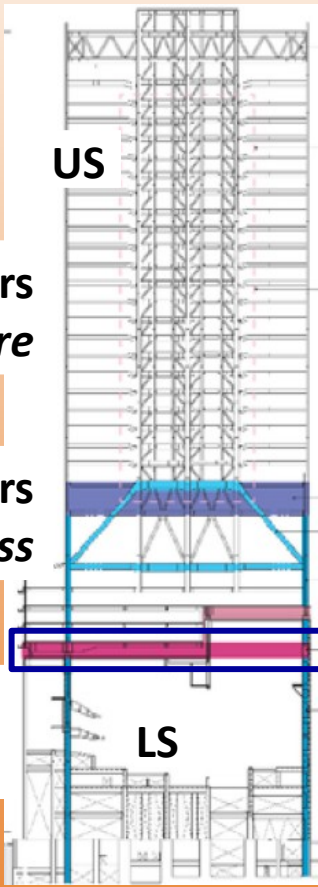
auditorium



Nakanoshima Festival Tower, Osaka (JAP)



upper-level floors
steel structure



intermediate-level floors
steel mega transfer truss

lower-level floors
src struct. with shear walls

US uffici - nucleo telaio controventato, frame tube esterno, tutto acciaio

LS auditorium - 16 «megacolonne» perimetrali in SRC

Nakanoshima Festival Tower, Osaka (JAP)

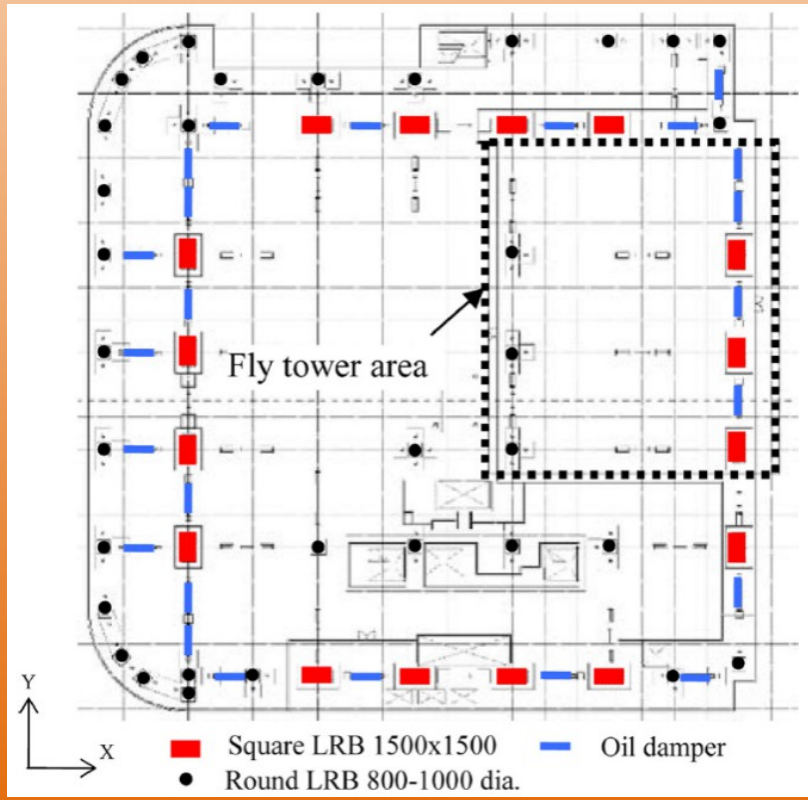
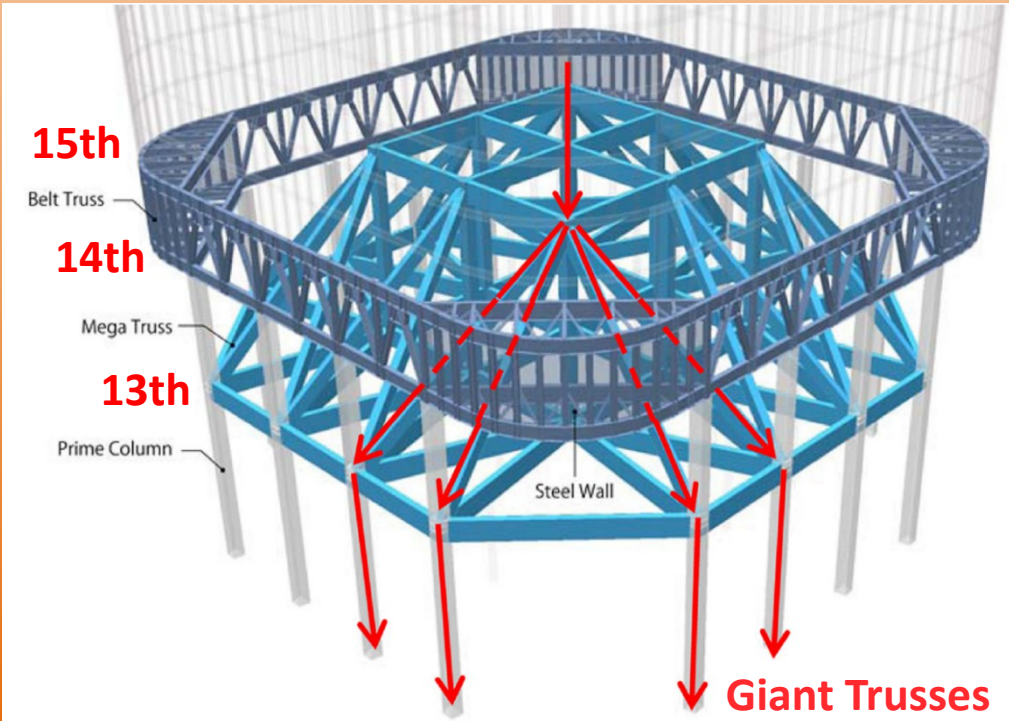
steel mega
transfer truss



square LRBs 1500x1500

sistema di isolamento

- 16 LRB Q1500x1500
- 34 LRB Φ 800 – 1000
- 24 smorzatori viscosi



IIS per adeguamento sismico di edifici strategici

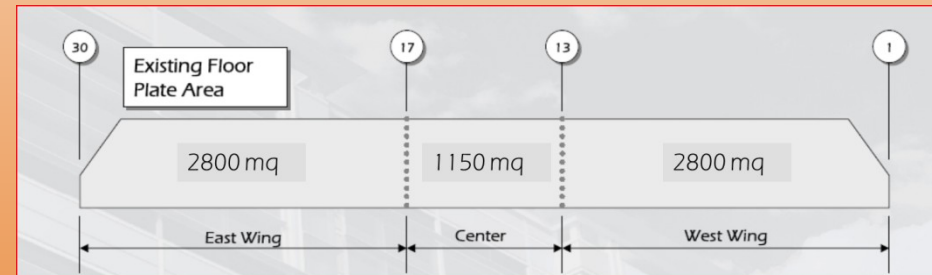
185 Berry Street Building, San Francisco (USA) – completed 2007



lower structure (LS) r.c. 3 floors

floor area 6700 sqm

required vertical addition: 13500 sqm

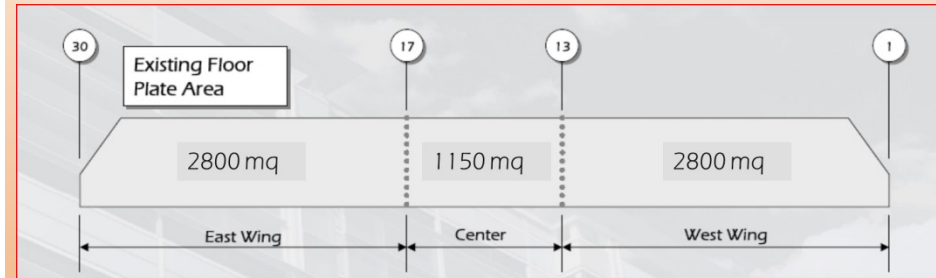


with conventional retrofit: 8400 sqm



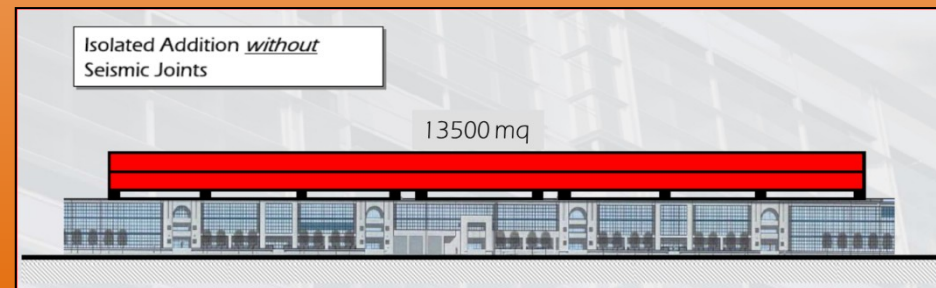
IIS per adeguamento sismico di edifici strategici

185 Berry Street Building, San Francisco (USA) – completed 2007



use isolation technology to turn 2-st. addition into a giant mass damper

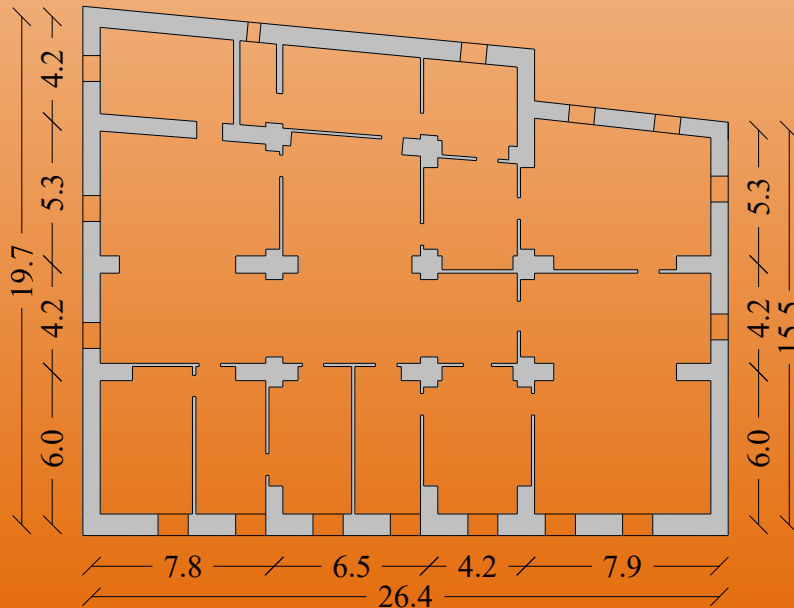
- max addition of floor area
- min retrofit in LS
- no disruption during works



SI vertical addition as a seismic retrofit strategy

research idea

explore the feasibility of IIS elevation as seismic retrofit strategy for **masonry buildings** - exploiting the stabilizing effect of additional gravity compression, without increasing, or even decreasing, the seismic base shear, thanks to the MD effect of the IS



case study

3-st. masonry office building

Plan 26.4 x 19.7 m

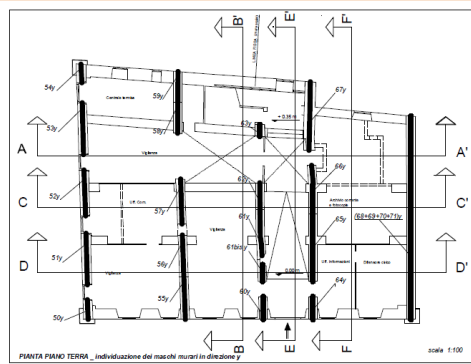
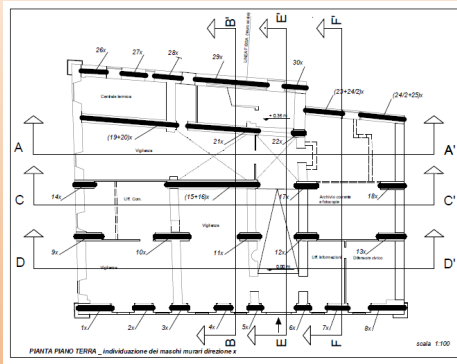
H_{tot} = 13.5 m

H_i = 4.5 m

swall = 65÷80 cm

case study: 3-st. existing masonry building

average compression stress under gravity loads (seismic condition)



masonry compression capacity : $f_0 = 2.10 \text{ MPa}$

gravity load $\rightarrow \sigma_c = 0.20 \div 0.40 \text{ MPa} \ll f_0$

large reserve of compression strength

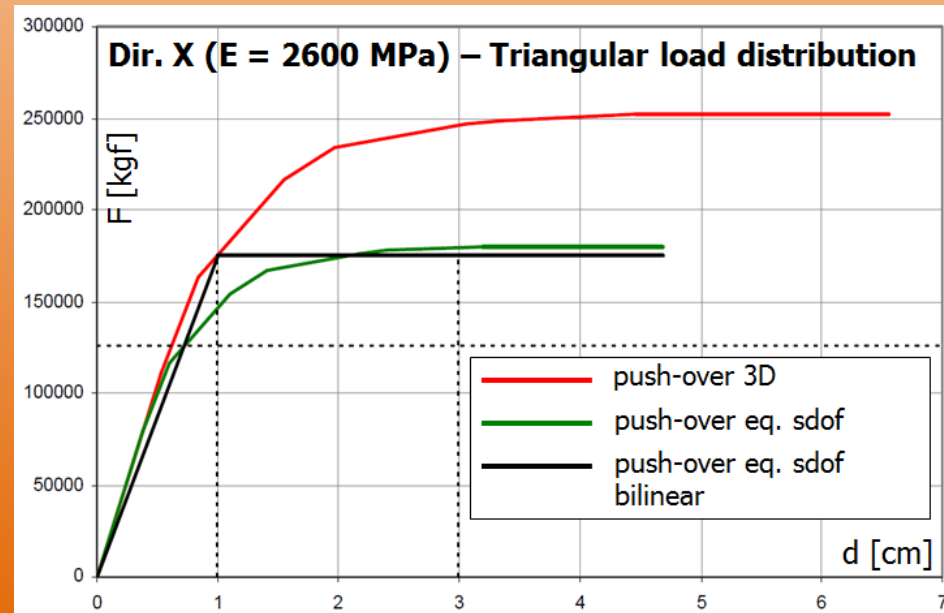
push over analysis and dynamic characterization

$$m_{LS} = 2900 \text{ t}$$

$$k_{LS} = k^* = 175000 \text{ kN/m (from PO Analysis)}$$

$$T_{LS} = 2\pi \sqrt{\frac{m_{LS}}{k_{LS}}} = 0.809 \text{ s}$$

$$\xi_{LS} = 0.05$$



simplified 3DOF IIS model

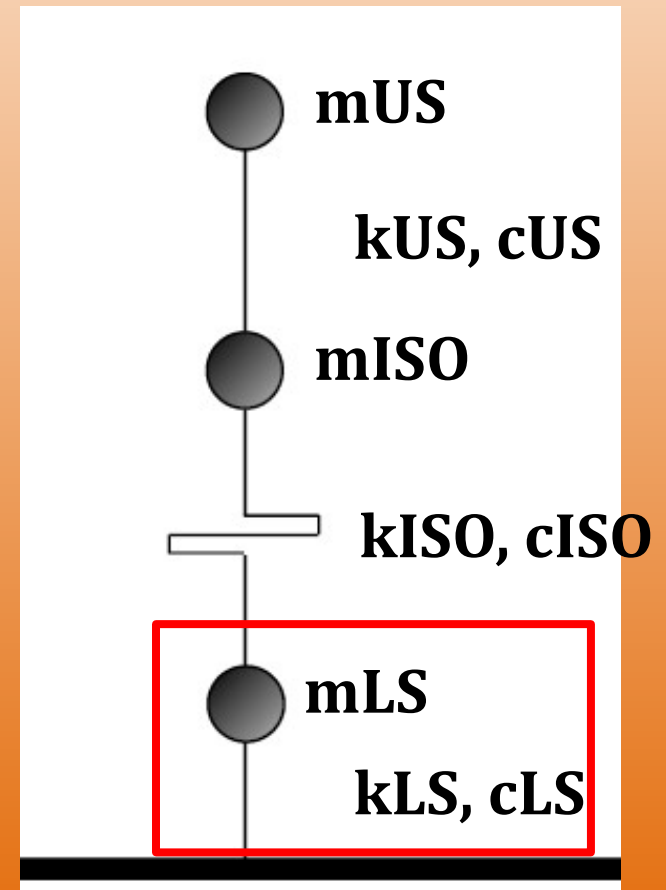
lower structure (LS) properties are known
(existing masonry building)

$$m_{LS} = 2900 \text{ t}$$

$$k_{LS} = 175000 \text{ kN/m}$$

$$\xi_{LS} = 0.05$$

$$T_{LS} = 2\pi \sqrt{\frac{m_{LS}}{k_{LS}}} = 0.809 \text{ s}$$



simplified 3DOF IIS model - parametric analysis

properties of upper structure (**US**) and isolation system (**ISO**) are the design unknowns → parametric analysis

design parameters

mass ratio, α :

$$\alpha = \frac{M_{ISO}}{m_{LS}} = \{0.1, 0.5, 1, 2\}$$

(from a very light to a very heavy upper structure)

stiffness ratio, K :

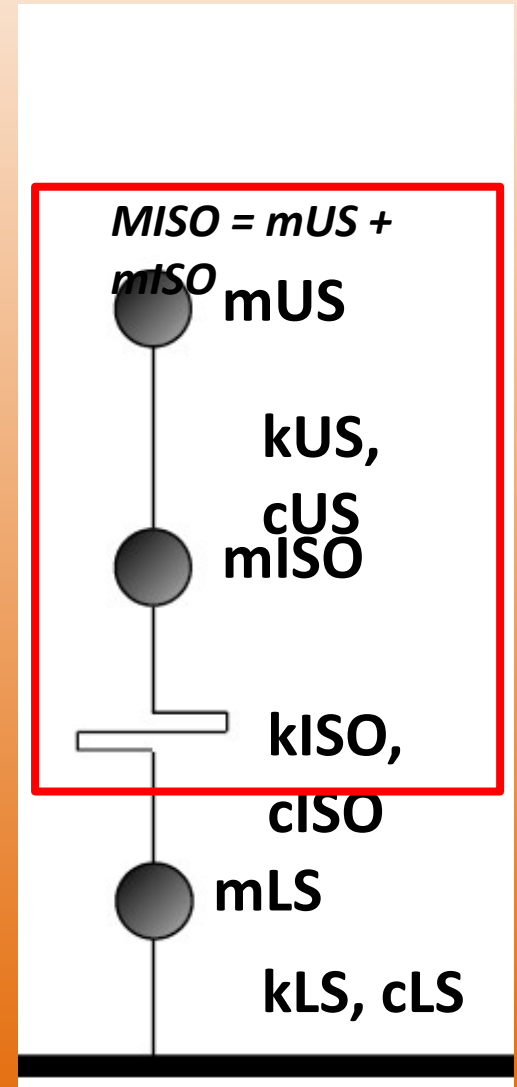
$$K = \frac{k_{US}}{k_{LS}} = \{0.1, 0.3, 0.5, 1.0\}$$

(from a very flexible to a very stiff upper structure)

isolation ratio, I :

$$I = \frac{T_{ISO}}{T_{US}} = \{3, 4, 5, 10, 16\}$$

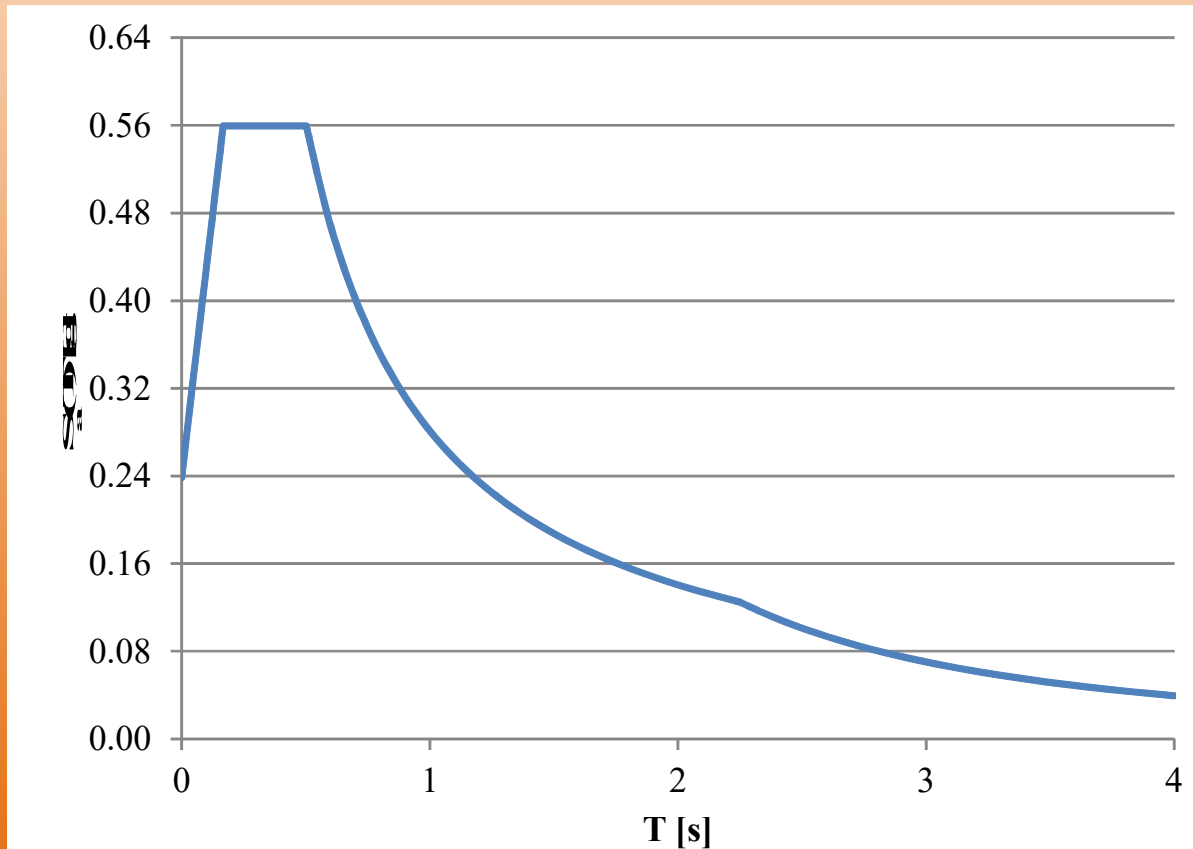
(from a min isolation ratio of 3 to very large values)



parametric analysis – response spectrum analysis

elastic response spectrum – horizontal acceleration (NTC08)

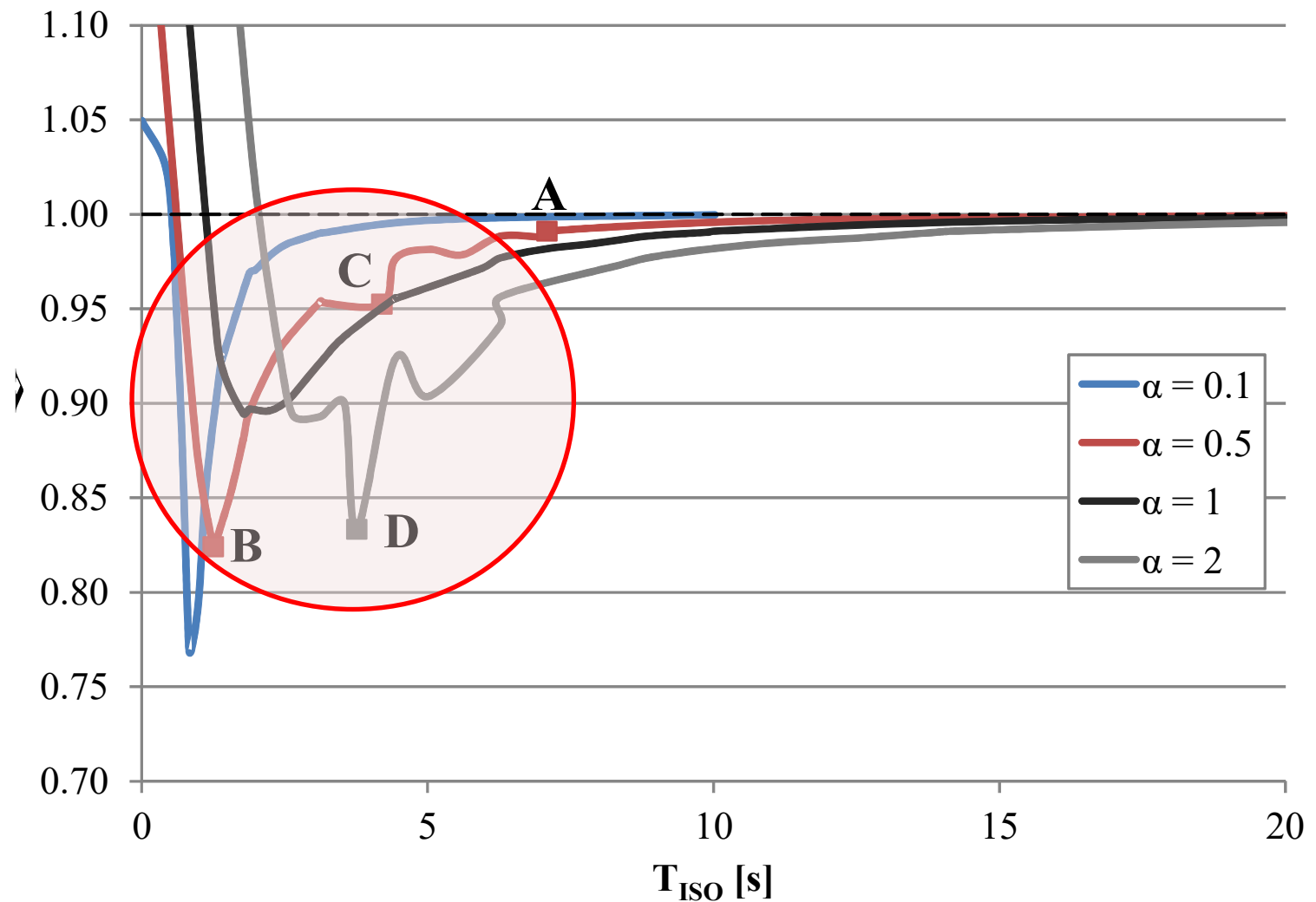
Pozzuoli (Naples, Italy) - $a_g=0.162g$; $F_0=2.347$; $TC^*=0.333s$; Soil C; Topogr. cat.T1



parametric analysis – response spectrum analysis

$$V = \frac{V_{b,3DOF HS}}{V_{b,SDOF LS}}$$

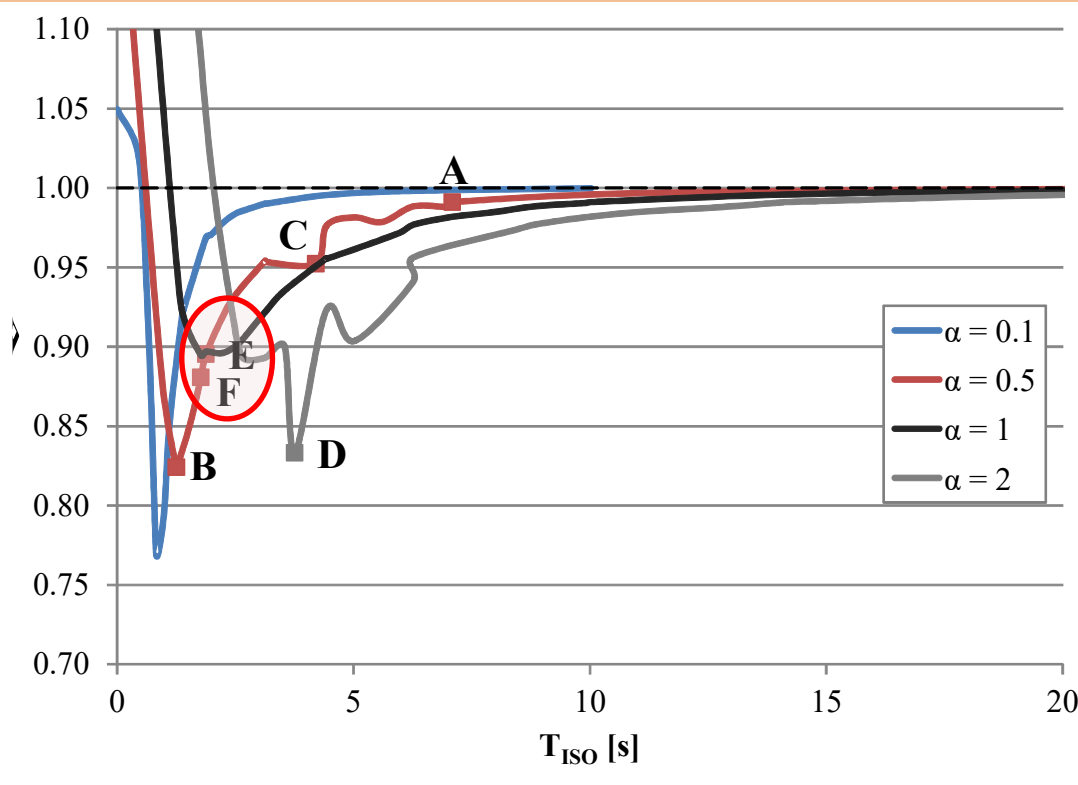
base shear in the 3DOF-IIS normalised to the SDOF-LS counterpart



design configuration for the US+ISO system

criteria for the US

- reduction of the seismic base shear V_b with respect to the original configuration
- adequate value of TISO (around 2.0 s) for properly isolating the US and obtaining the MDE
- US period far from LS period for preventing MCE
- mass ratio around 0.5 for maximizing MDE and construction feasibility (added floors ≤ 3)



case E: $\alpha=0.5$, $K=0.5$, $I=3$

$T_1=2.040$ s; $T_{ISO}=1.880$ s; $v=0.895$

case F: $\alpha=0.5$, $K=1.0$, $I=4$

$T_1=1.913$ s; $T_{ISO}=1.772$ s; $v=0.881$

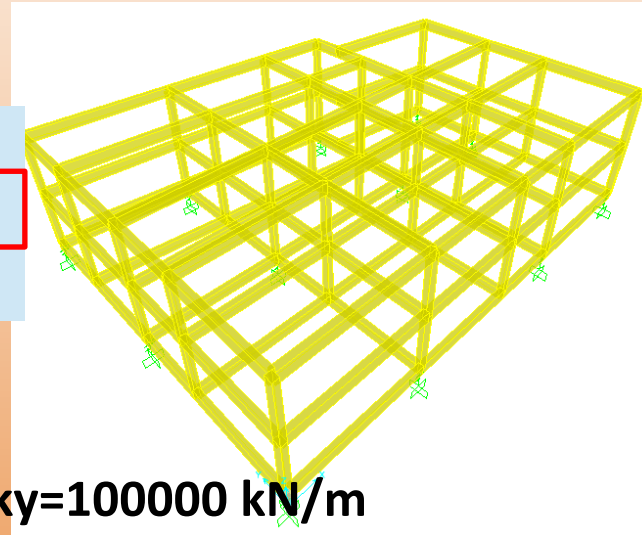
design configuration for the US+ISO system

case E: $\alpha=0.5$, $K=0.5$, $I=3$

$T_1=2.040$ s; $T_{ISO}=1.880$ s;

$v=0.895$

Material	Structure	Floors	Columns	Shear walls	Beams
Concrete	Frame	2	30x40	-	30x60
Steel	CBF	3	HEB 260	-	IPE 550



3DOF IIS: $k_{US}= 87500$ kN/m – 3D US: $k_x=84000$ kN/m; $k_y=100000$ kN/m

case F: $\alpha=0.5$, $K=1.0$, $I=4$

$T_1=1.913$ s; $T_{ISO}=1.772$ s; $v=0.881$

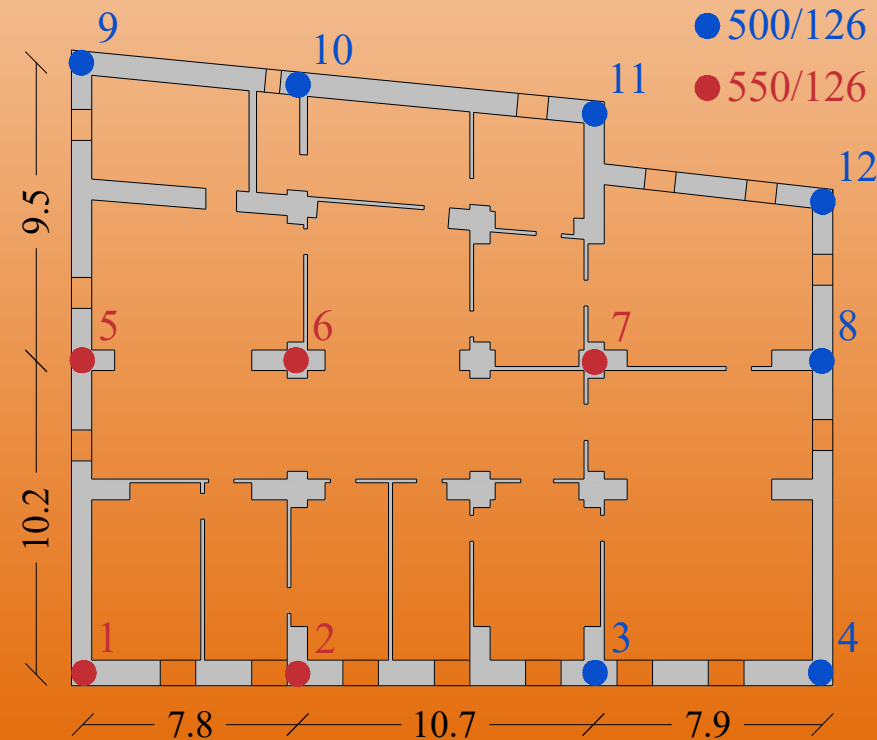
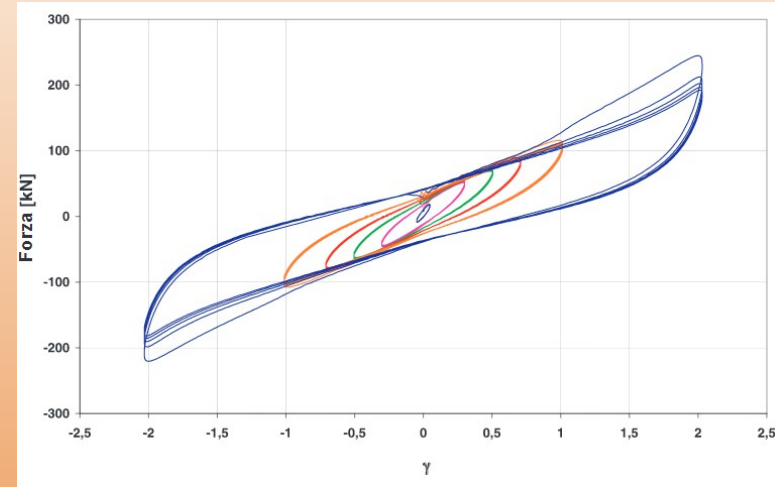
Material	Structure	Floors	Columns	Shear walls	Beams
Concrete	Shear wall	2	30x40	30x150	30x60
Steel	CBF	3	HEB 260	-	IPE 550

design configuration for the US+ISO system

criteria for the IS

- large dimensions of isolators
- large distance between isolators
- isolators at the intersection of walls
- $G_m \equiv G_k$

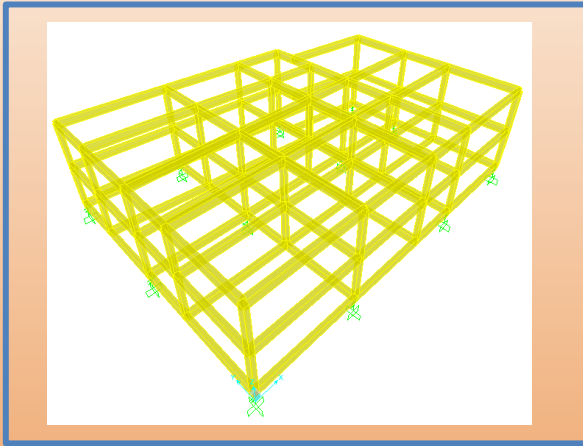
SI-N, FIP Industriale (G = 0.80 MPa)



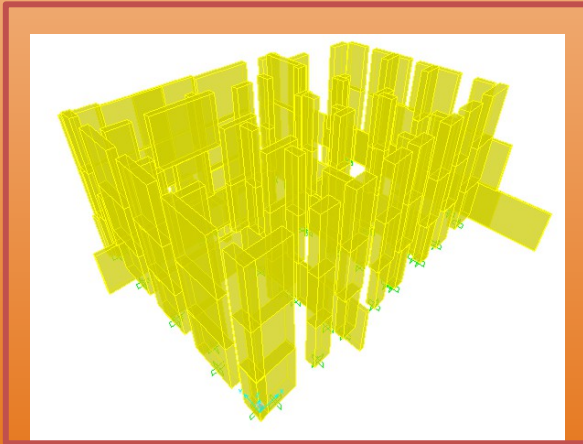
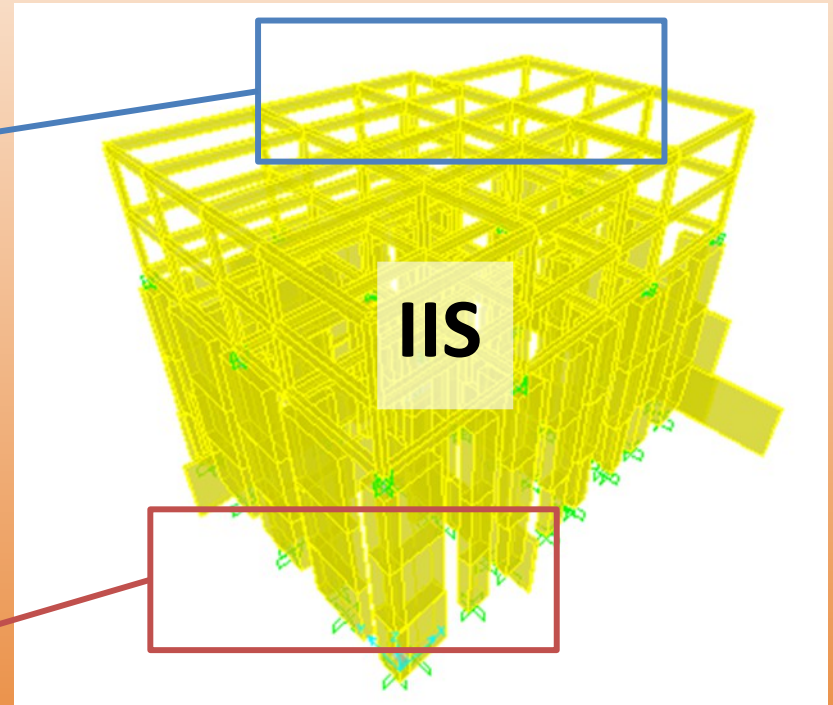
Type	500/126	550/126
D [mm]	500	550
t [mm]	126	126
S ₁	20	20
S ₂	3.97	3.37
k _{eq} [kN/mm]	1.25	1.51



three-dimensional analyses



ISO+US



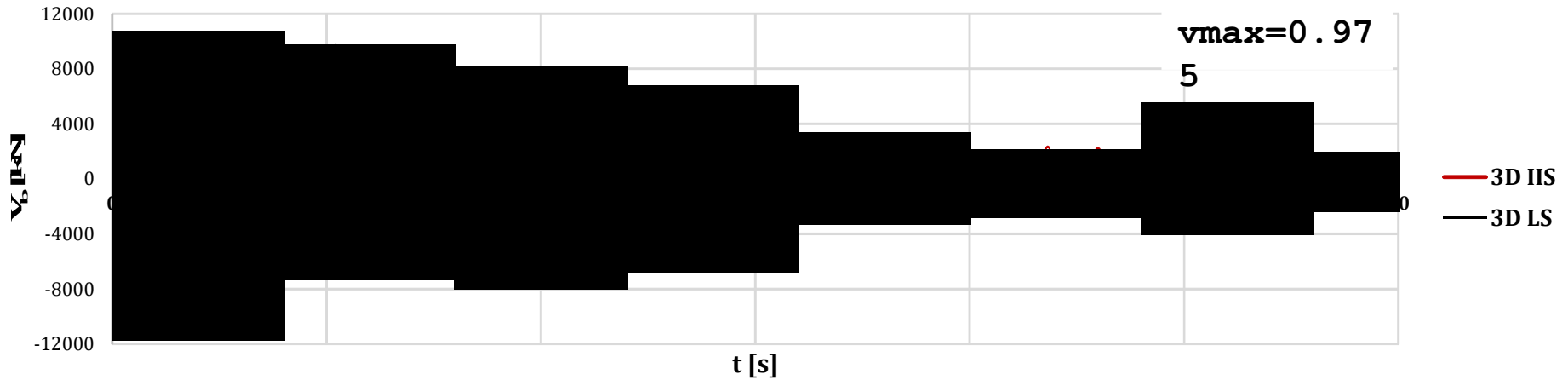
LS

- modal analysis
- response spectrum analysis
- time history analysis

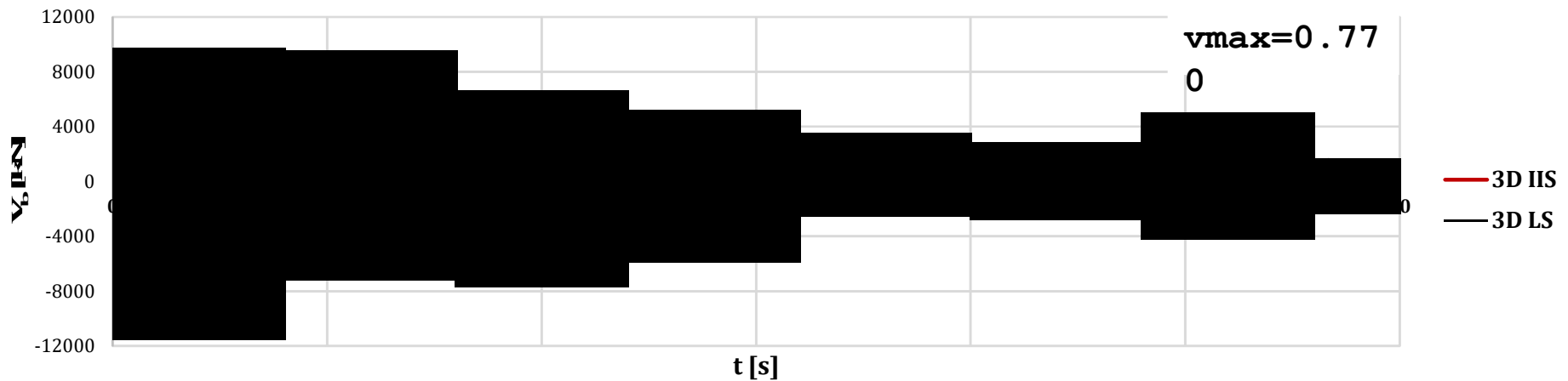
3D time history analysis - El Centro

3D IIS vs. 3D LS - base shear history

Time History X

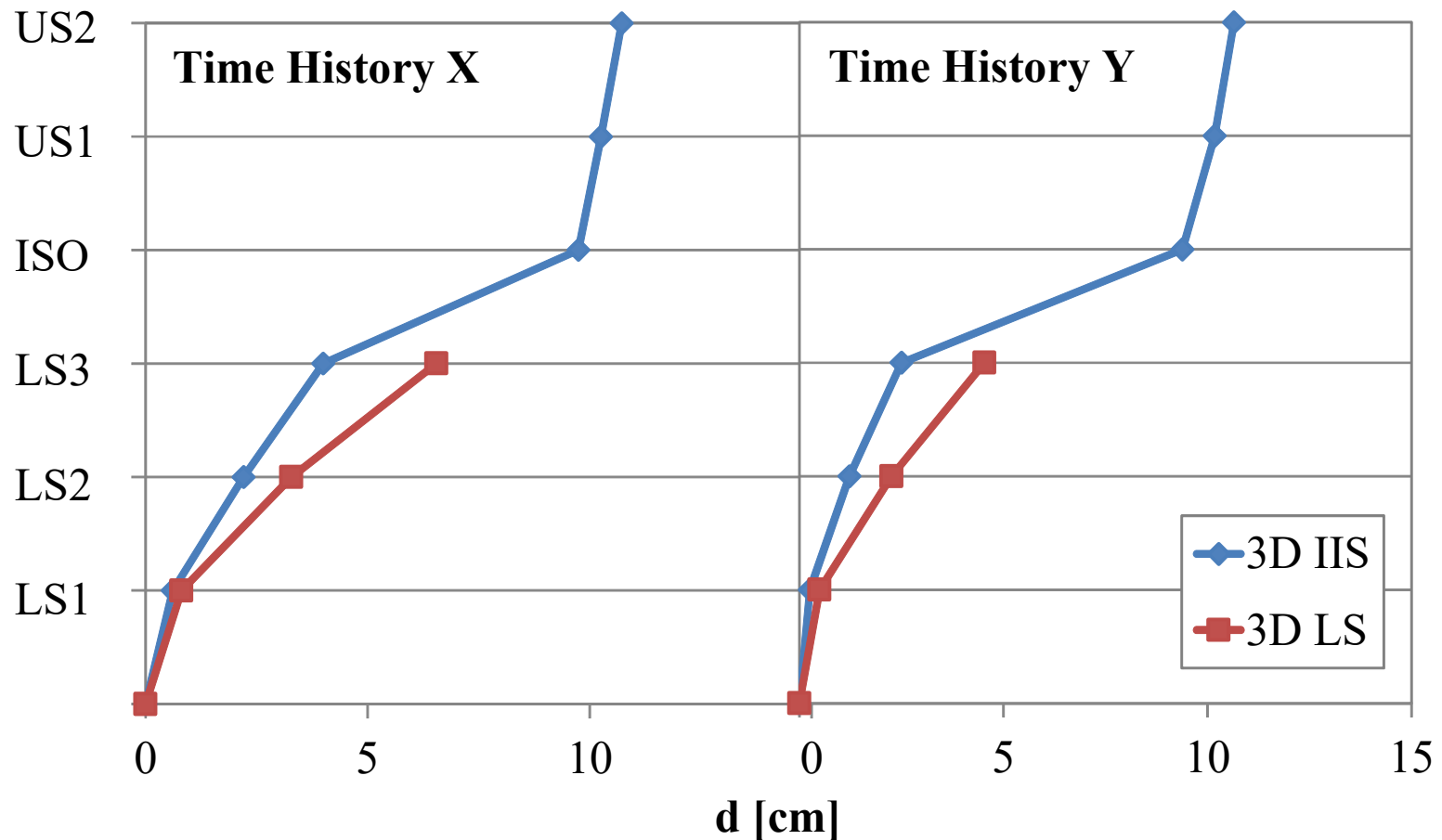


Time History Y



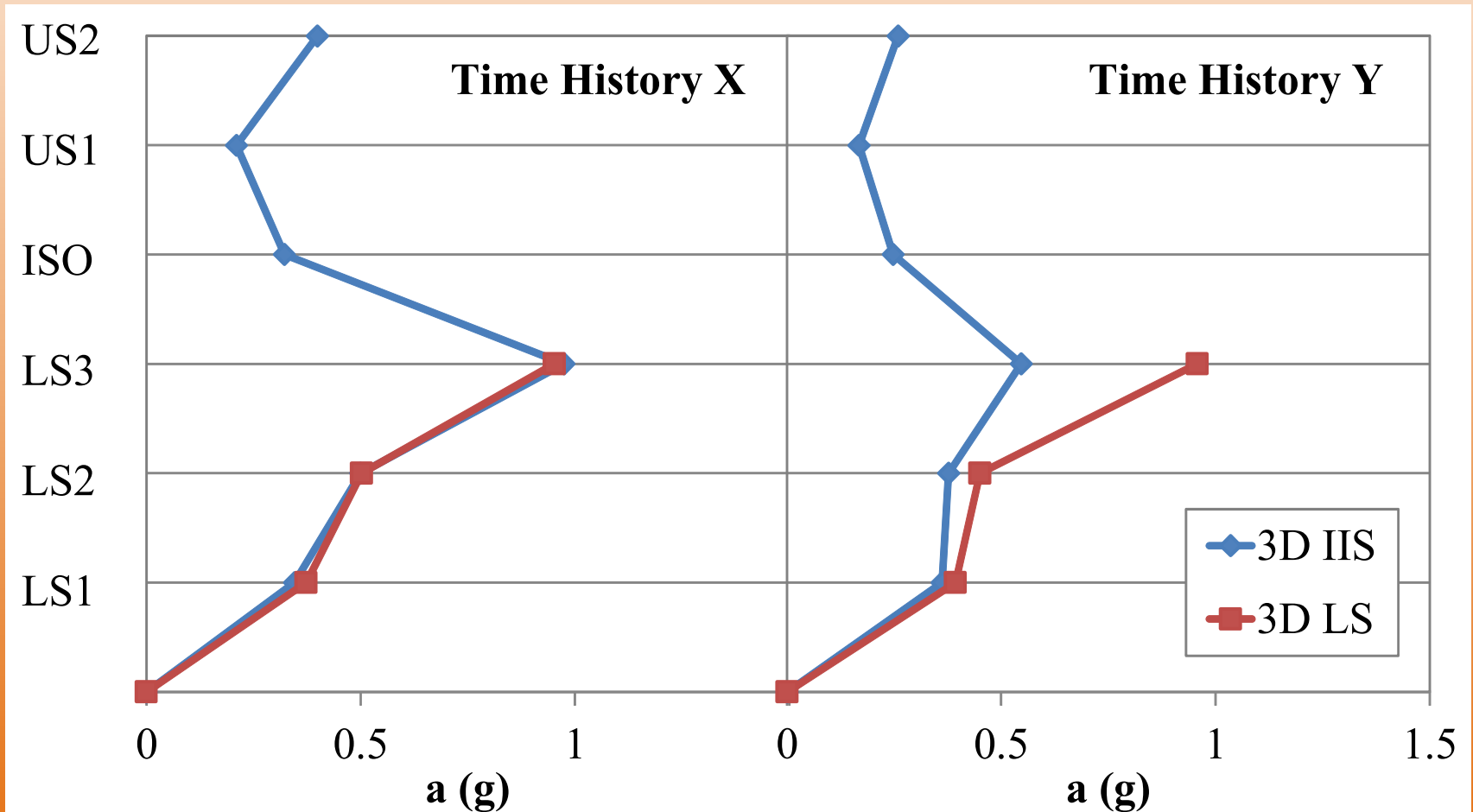
3D time history analysis - El Centro

3D IIS vs. 3D LS - drift peak values



3D time history analysis - El Centro

3D IIS vs. 3D LS - acceleration peak values



observations and conclusive remarks

- IIS feasible and beneficial for the retrofit of existing masonry buildings that have large safety margin with respect to gravity load condition
- IIS reduces seismic base shear and displacements in the existing lower structure thanks to the **Mass Damper Effect**, and reduces accelerations in the upper structure, thanks to the **Isolation Effect**
- Seismic response is minimized for TISO not so large; the “perfect” isolation is not as effective as the “non perfect” one
- However MDE arises when adequate isolation ratio is adopted, namely $I \geq 3$
- Contrarily to BIS, higher modes in IIS are not negligible
- **Coupling of higher modes** (MCE) only arises when first periods of LS and US (as standalone structures) are very close, independently on ISO characteristics – thus this detrimental effect can be predicted and avoided
- Other TH analyses have shown a significant robustness of the system

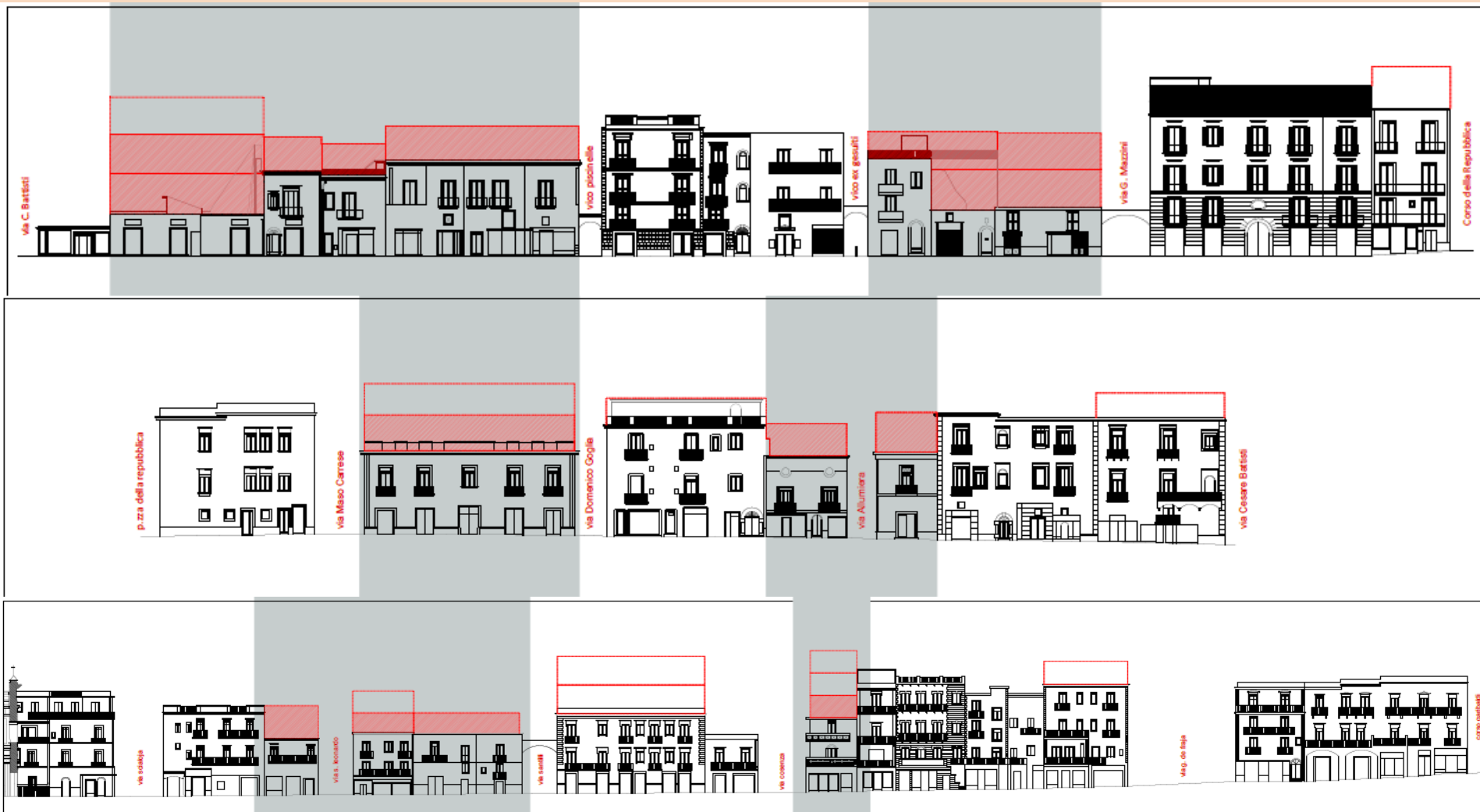
sviluppi in corso – il caso di Pozzuoli



sviluppi in corso – il caso di Pozzuoli

Pozzuoli, Napoli. Piano Urbanistico Attuativo 2012

«ricomposizione volumetrica" degli edifici che hanno subito parziale demolizione a seguito degli eventi sismici e bradisismici degli anni '80



sviluppi in corso – il caso di Pozzuoli

the city above the city



GRAZIE PER L'ATTENZIONE,

Prof. Ing. Elena Mele

Università di Napoli Federico II

Telefono 081.7682448

E-mail elena.mele@unina.it