The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific and
Cultural Organization

IAEA
International Atomic Energy Agency

**2142-19**

**Advanced Conference on Seismic Risk Mitigation and Sustainable Development**

***10 - 14 May 2010***

# On the need for a reliable seismic input assessment for optimized design & retrofit of seismically isolated civil and industrial structures, equipment and cultural heritage

Alessandro Martelli

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The Abdus Salam International Centre for Theoretical Physics

IAEA

*Advanced Conference on Seismic Risk Mitigation and Sustainable Development*
*ICTP, Trieste, Italy, May 10 – 14, 2010*

↑ The new San Giuliano di Puglia school, protected by base seismic isolation

# On the need for a reliable seismic input assessment
## for optimized design & retrofit of seismically isolated civil and industrial structures, equipment and cultural heritage

Buildings collapsed in Abruzzo


*Alessandro Martelli*

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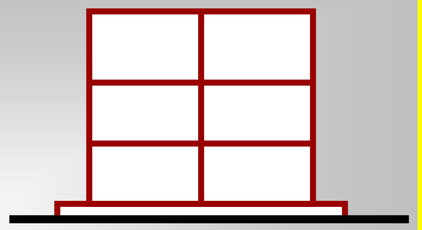
- *President, GLIS; Past President & Coordinator of the Territorial Section for the EU and other Western European Countries, ASSISi; Coordinator, EAEE-TG5*

# ITALIAN STRATEGIES OF SEISMIC PROTECTION

## CONVENTIONAL

**Structural damage accepted**

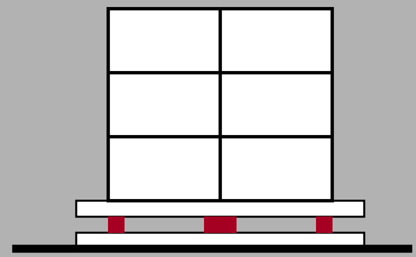


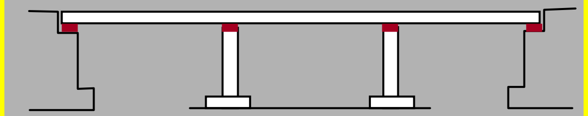
***Eurocode 8 and new Italian code***

***(of obligatory use since Summer 2009):***

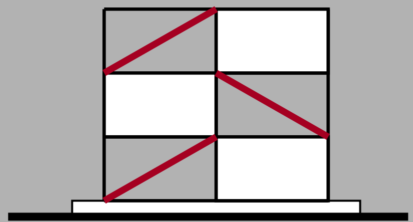
*the structure shall be designed to withstand the seismic action  with 10% in 50 years arrival probability without collapsing*

## SEISMIC ISOLATION (SI)





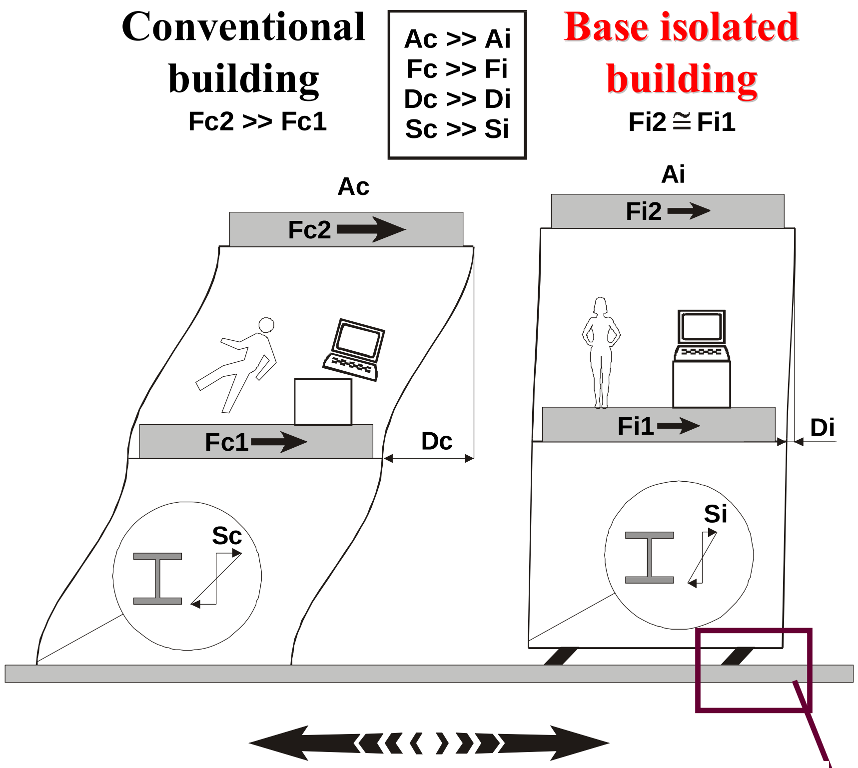
## ENERGY DISSIPATION (ED)



- **No structural damage**
- **Special devices**

**OTHER ANTI-SEISMIC DEVICES:**

- **Shape Memory Alloy Devices (SMADs)**
- **Shock Transmitter Unites (STUs)**

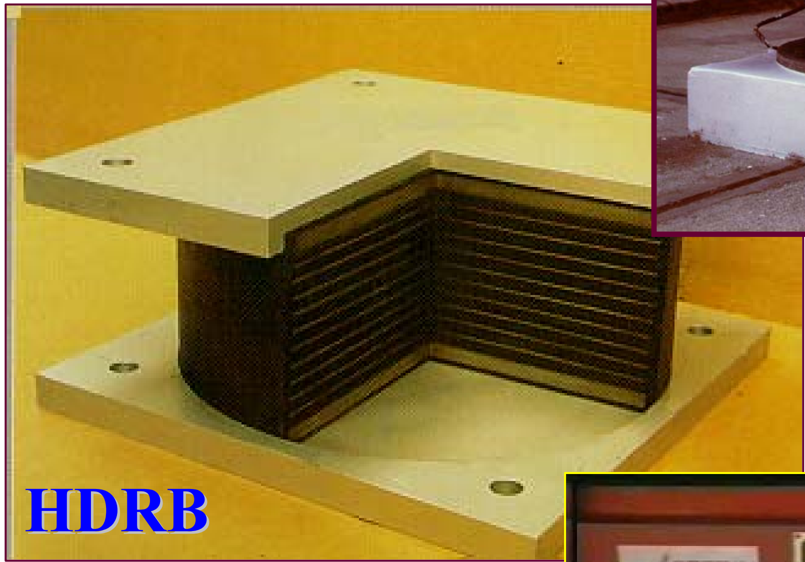



HORIZONTAL SEISMIC MOTION

**REDUCTION OF SEISMIC VULNERABILITY:**
***horizontal seismic isolation* (SI)**

## Case of steel-laminated High Damping Rubber Bearings (HDRBs)

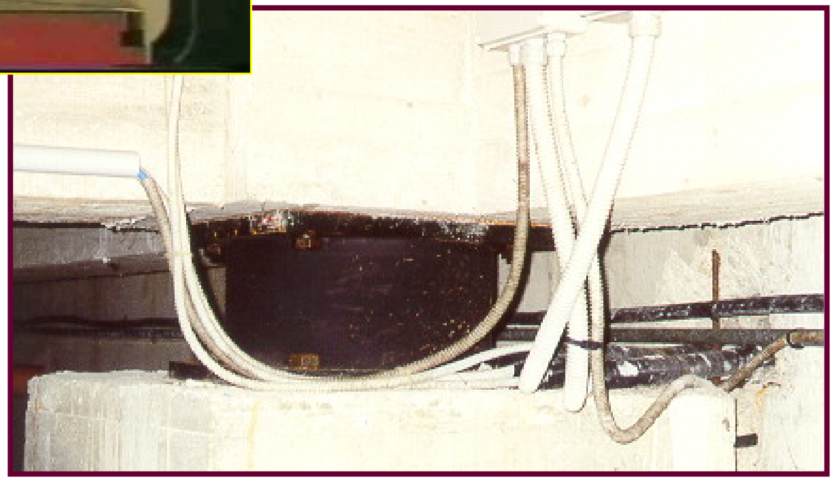
**BRITE EURAM II Project, 1993 (ENEA & others)**




*Telecom Italia, Ancona, 1990*

*Steel-laminated High Damping Rubber Bearings*


*Most used SI system in Italy for buildings*

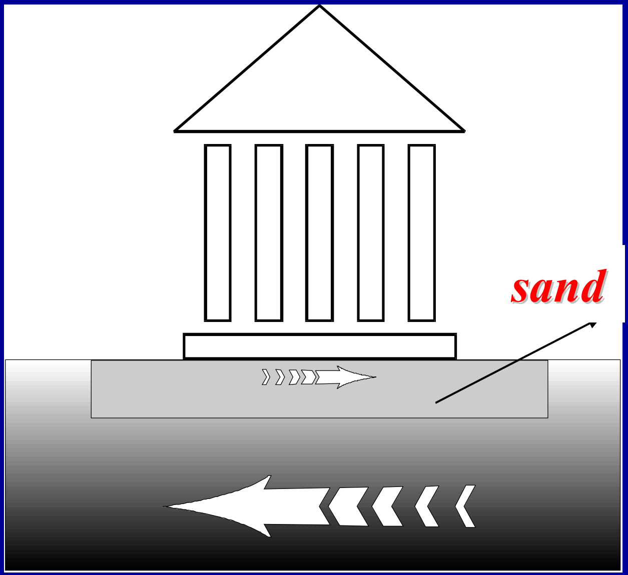



Rubber bearings: type test at FIP Industriale Laboratories
& on-site test of an isolated building at Solarino (Syracuse)

# SEISMIC ISOLATION IS NOT A NEW CONCEPT!

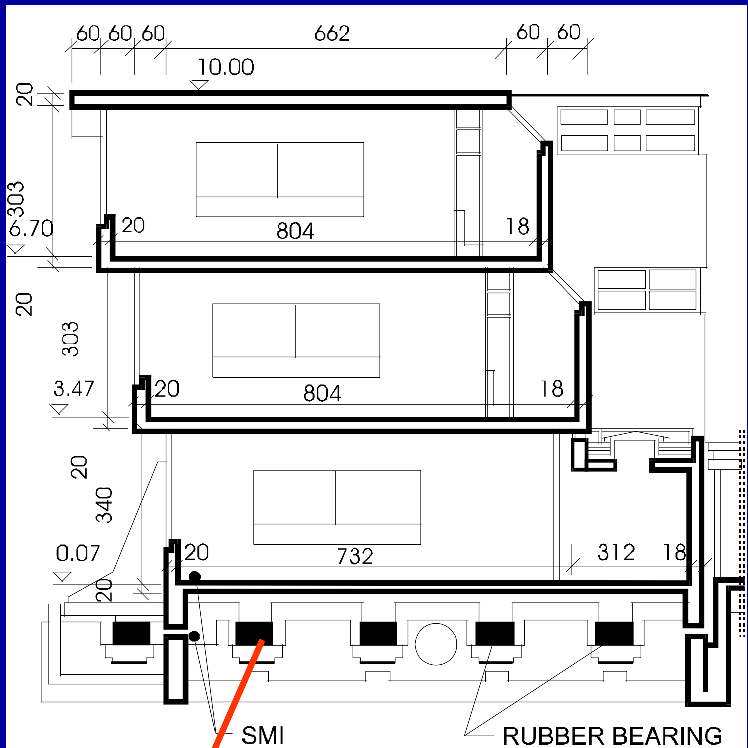
**Gaius Plinius Secundus, Naturalis Historia:**

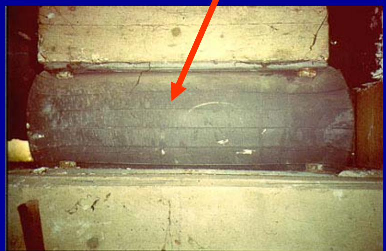
***"Grecae magnificentiae vera admiratio extat templum Ephesiae Dianae CXX annis factum a tota Asia.***
***In solo id palustri fecere, ne terrae motus sentiret aut hiatus timeret, rursus ne in lubrico atque instabili fondamenta tantae molis locarentur, calcatis ea substravere carbonibus, dein velleribus lanae".***

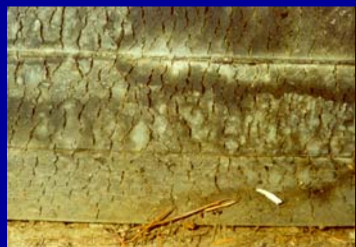




**Ancient Greek temples, Chinese monasteries, temples and bridges, Incas, Persian and Anatolian constructions and Italian temples seem to have been protected by rough sliding or rolling seismic isolation systems (sand or tree trunks under the structure, rubble layers in the walls): some are still standing!**

# 1st MODERN APPLICATION OF SEISMIC ISOLATION:
## Pestalozzi primary school *(Skopje, Macedonia, years 1960s)*





*LDRBs donated by Switzerland after the 1963 Skopje earthquake*

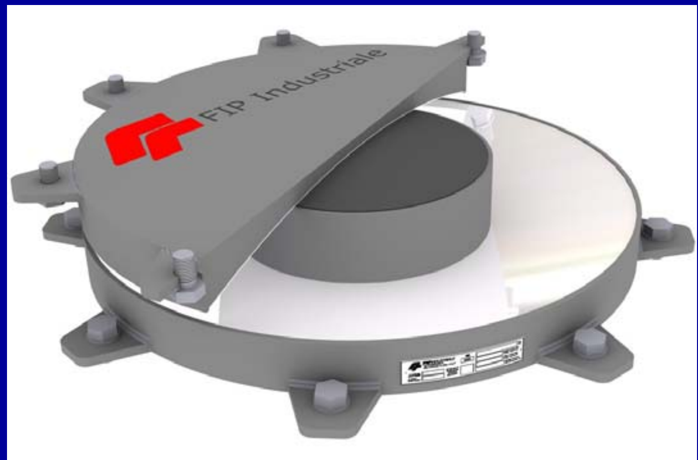
*The original (very poorly reinforced and rather deteriorated) LDRBs were replaced by HDRBs in 2007*

*An original LDRB still in position (right) and a new HDRB immediately after its installation (left)*

# Curved Surface Sliders (CSSs)

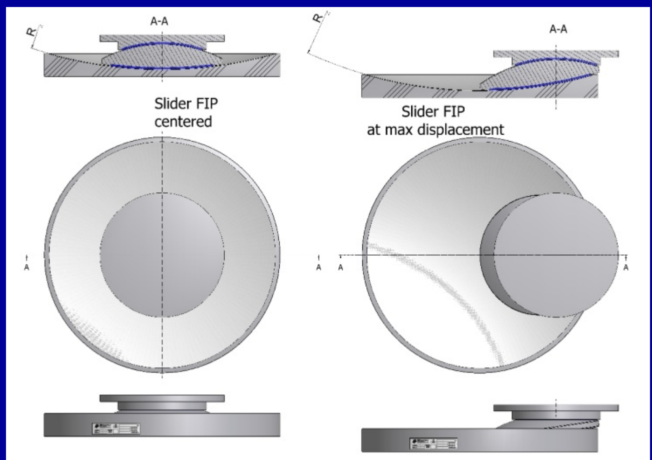
*(derived from Friction Pendulum System – FPS)*

**1 or 2 concave sliders and a steel rocker of a special sliding material**



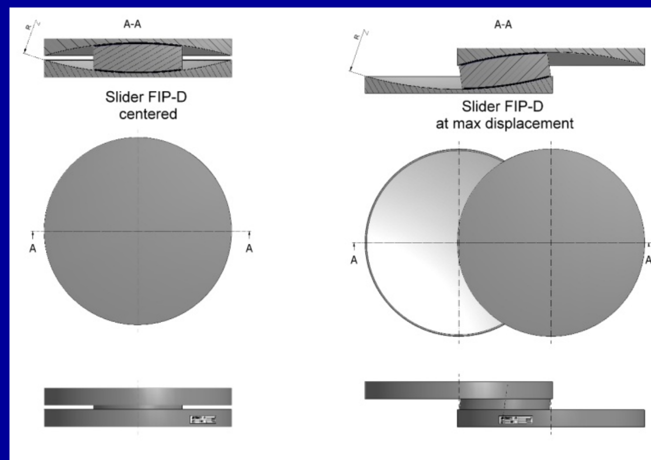

**(CSS behavior is *theoretically* independent of the structure weight and eccentricities)**

Single CSS




Double CSS

(for very large displacements)



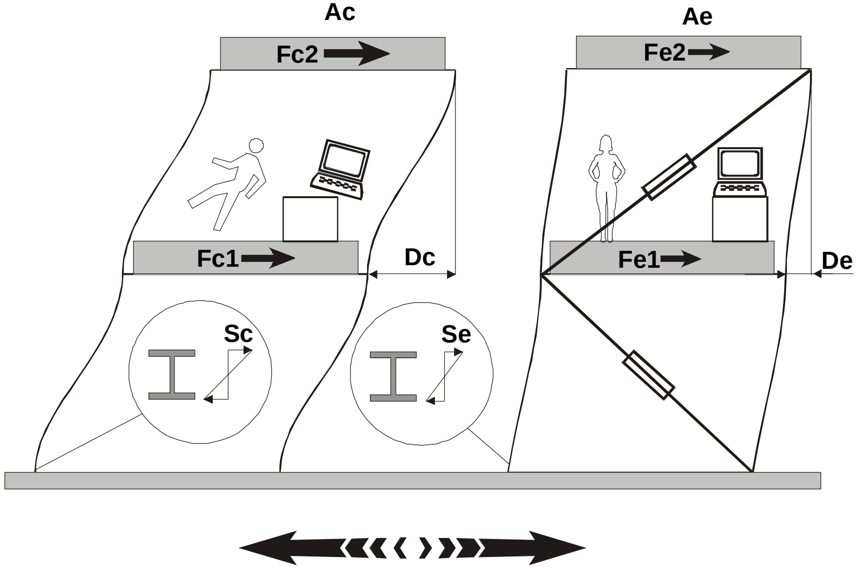
# Dynamic Type Test at Eucentre (Pavia) & tests at UCSD (San Diego, CA, USA)

## Jyorakuin (Tokyo Tachikawa)

*Wooden Buddhist temple erected in 2004 on a r.c. slab supported by:*

- *20 sphere recirculation isolators of 3 sizes ($T_{isolation}$ > 10 s)*
- *3 pairs of superposed Rubber Bearings (RBs) (only with re-centering function)*
- *1 big Lead Damper (LD)*

# REDUCTION OF SEISMIC VULNERABILITY: *Energy Dissipation* (ED)




**One of the twin 29-storey towers (h = 120 m) of the ENEL Headquarters at Naples, with suspended central core.**

***Each core was protected from excessive rotation by 116 + 116 Elastic-Plastic Dampers (EPDs) in <u>1993.</u>***

***Test of a building mock-up provided with electro-inductive dampers on the ENEA shake table***

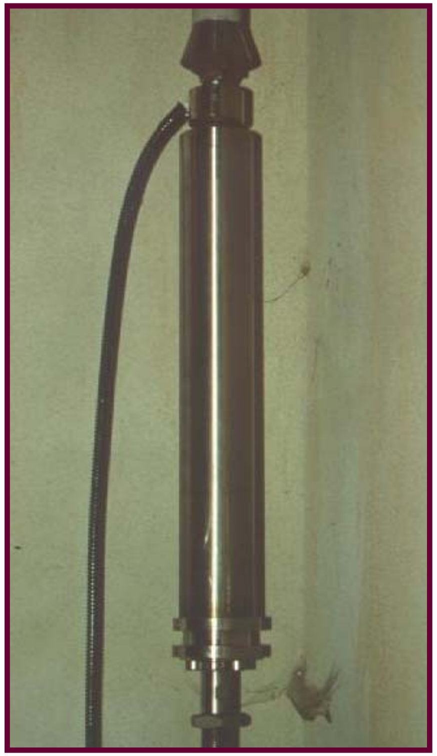
**NON-APPLICABILITY OF SI:**

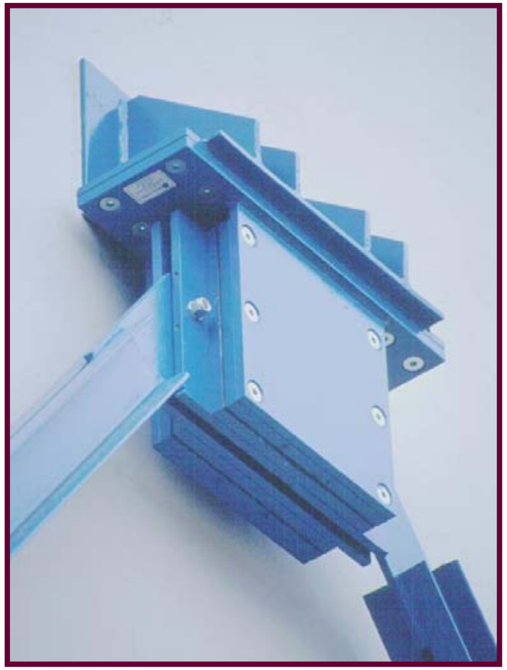
***(1) Too flexible structure; (2) Too soft soil***

***(3) Absent or non feasible lateral gap***

*Elastic-Plastic Dampers (EPDs)*

*Shape Memory Alloy (SMA) force limiting Devices (SMADs)*





*Visco-Elastic Dampers (VEDs)*

*Viscous Dampers (VDs)*

*"Shock Transmitter Units" (STUs)*

# Rion-Antirion Link
# Greece

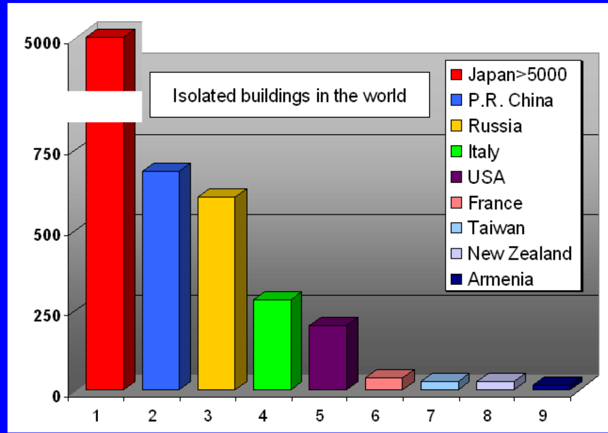

*Test at UCSD – USA*

*The Achalia-Ilia Earthquake of June 8, 2008*

# Application of anti-seismic systems

***<u>Over 10,000</u>, to new & existing structures:***

- ***Bridges and viaducts***
- ***Industrial plants & components, in particular the high risk ones***




- ***Single masterpieces***

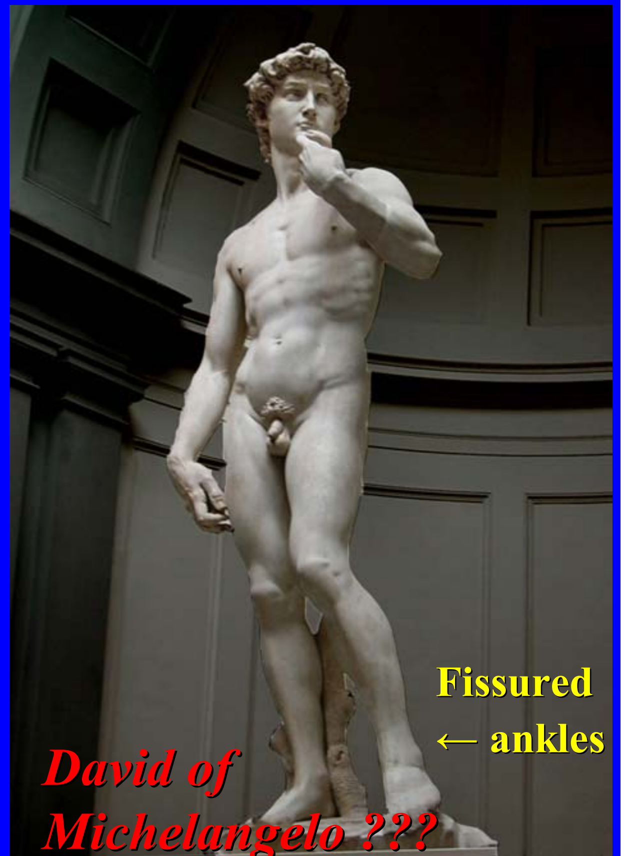
***Rion-Antirion, Greece (Italian VDs and other devices)***

***Tests on an isolated tank (ENEA collab.)***

- ***Buildings , including cultural heritage***


***First Japanese isolated hospital, Kushiro City***

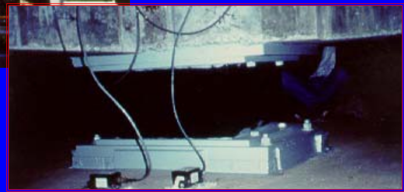
***St. Francis, Assisi (SMADs & STUs)***



***David of Michelangelo ???***

**Fissured ← ankles**

# CONFIRMATIONS OF SI EFFICIENCY: USA & Japan



*Lead Rubber Bearings (LRBs)*

**USC Hospital at Los Angeles,** ***Northridge earthquake, California, USA, ~ 30 km from epicenter (1994): no damage, $A_{is}/A_c$~ 1/9***

*Low Damping Rubber Bearings (LDRBs) & Elastic-Plastic Dampers (EPDs)*

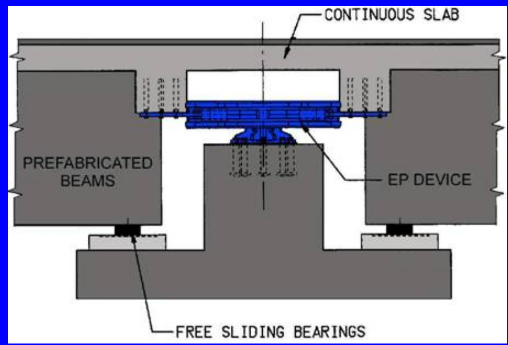
**Ministry of Posts and Tele-comuni-cations of Sanda City,** ***Hyogo-ken Nanbu earthquake, Kobe, Japan, ~ 30 km from epicenter (1995): no damage, $A_{is}/A_c$~1/9)***

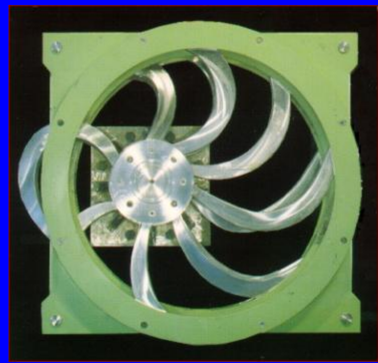

*Rubber Bearings (RBs) & Sliding Devices (SDs)*

**R.c. building erected at Ojiya City (Japan) in 1996,** ***Niigata-ken Chetsu earthquake (2004): no damage***

**A similar behavior was shown by further isolated structures**

# Half-moon-shaped EPDs manufactured in Italy installed in the Bolu viaduct of the Istanbul – Ankara freeway, which was under construction in 1999



***EPD in a failure test***

***They saved the viaduct from collapsing during the 1999 Duzce earth-quake (M=7.2), although its intensity (0.87 g) was more than twice the design value (0.4 g).***

***Thus, retrofit was possible***

**Retrofit was performed by means of FPS isolators with 700 mm diameters (900 mm at fault crossings).**
**2 isolators were inserted at the intermediate piers between the diaphragms and 4 at the expansion joints**

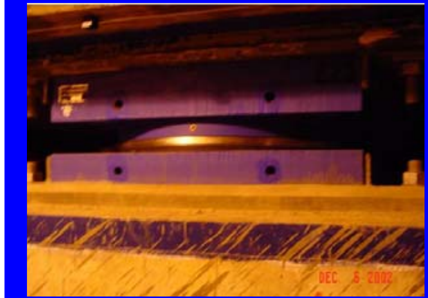
# LAST CONFIRMATIONS OF SI EFFICIENCY:

## Wenchuan earthquake, P.R. China, May 12, 2008 (*unpredicted hazard*) and 8.8 Central Chilean earthquake, February 27, 2010

*Collapse and heavy damage of conventionally founded buildings*

*Full integrity of the 3 (2 r.c. and 1 masonry) existing isolated buildings*

# ISOLATED HIGH RISK INDUSTRIAL PLANTS



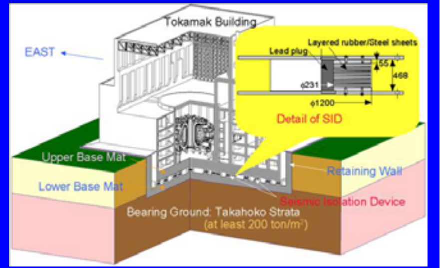
*Revithoussa, Greece, years 1990s, 2 tanks ($\Phi$ = 20 m, at 70 m under ground level) each with 212 FPSs*

*Inchon, South Korea, 3 tanks each with 392 HDRBs (further 10, each with 150 HDRBs, at Pyeong Taek)*

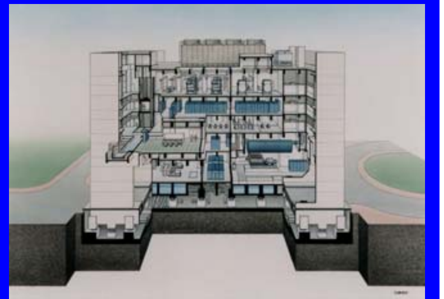

*Aliaga-Izmir, Turkey*


*Guangdong, P.R. China*

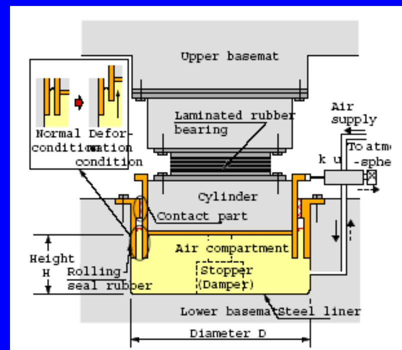
**Liquefied Natural Gas (LNG) tanks**




*ITER, Cadarache, France*

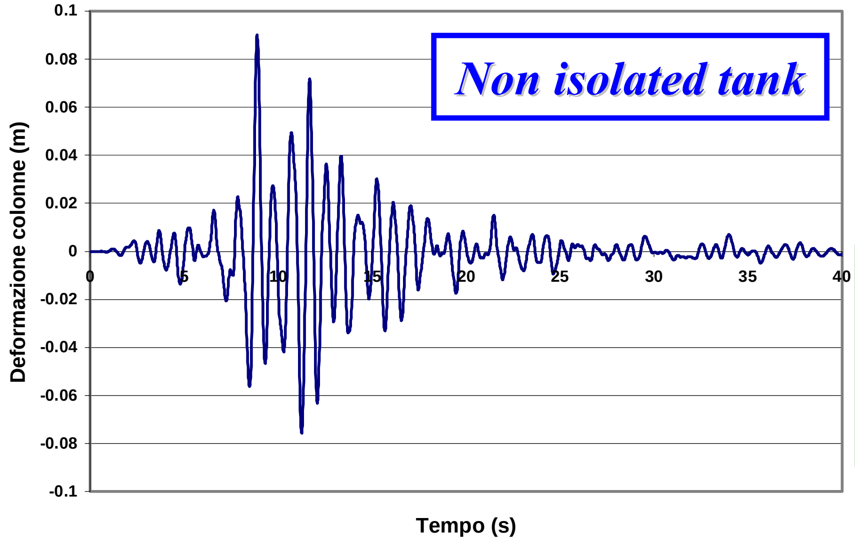


*Nuclear Fuel Related Facility, Japan*



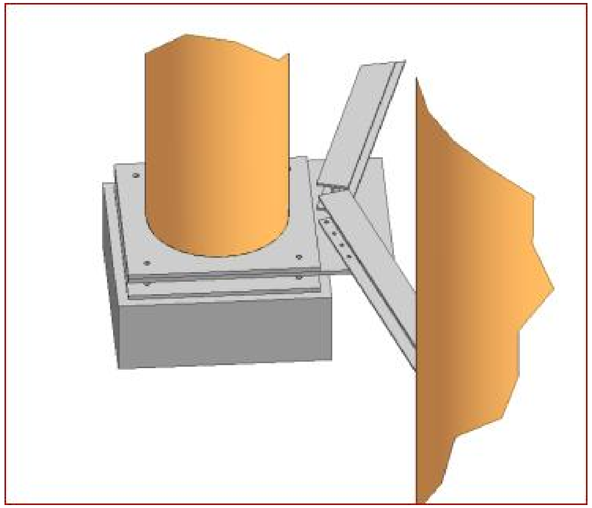

*DFBR, Japan*

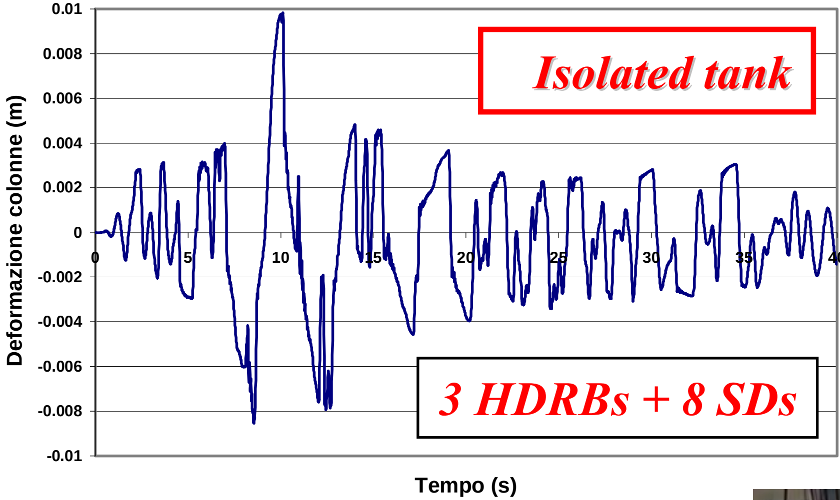
**Nuclear plants**




*Column deformations with & without SI*

*Aspropyrogos, Greece (INDEPTH Project - ENEA et al.)*

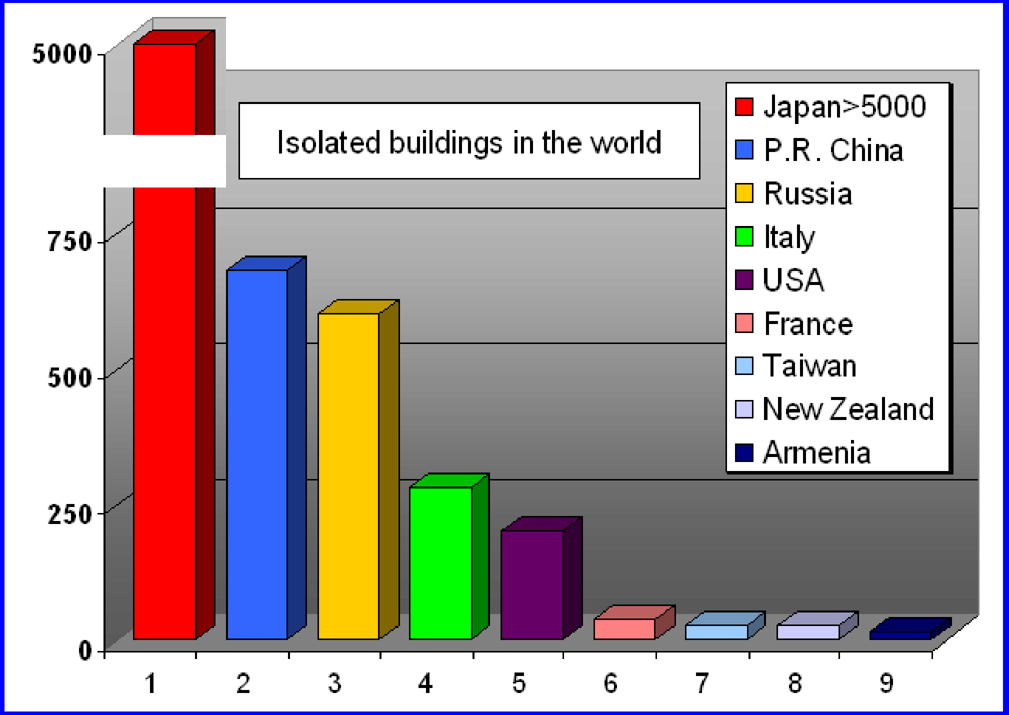




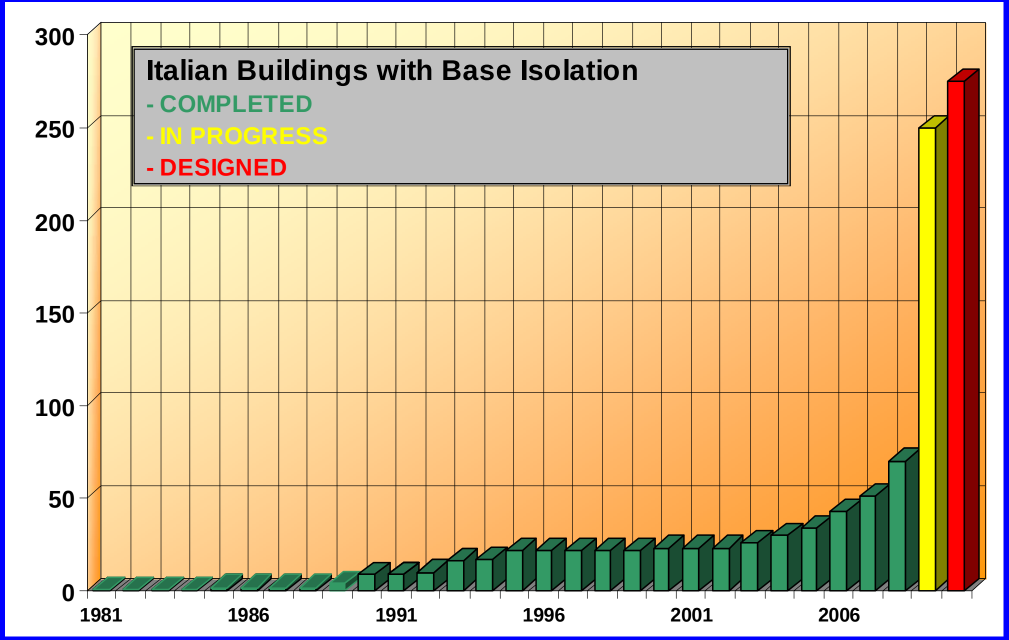

**Seismic response of a real LNG Tank at Priolo, Sicily (<u>ISI Project – ENEA et al.</u>)**

*Need for checking the compatibility of displacements with piping requirements.*

# BUILDING APPLICATIONS OF SEISMIC ISOLATION




*Overall number of isolated buildings in the most active countries (November 2009)*

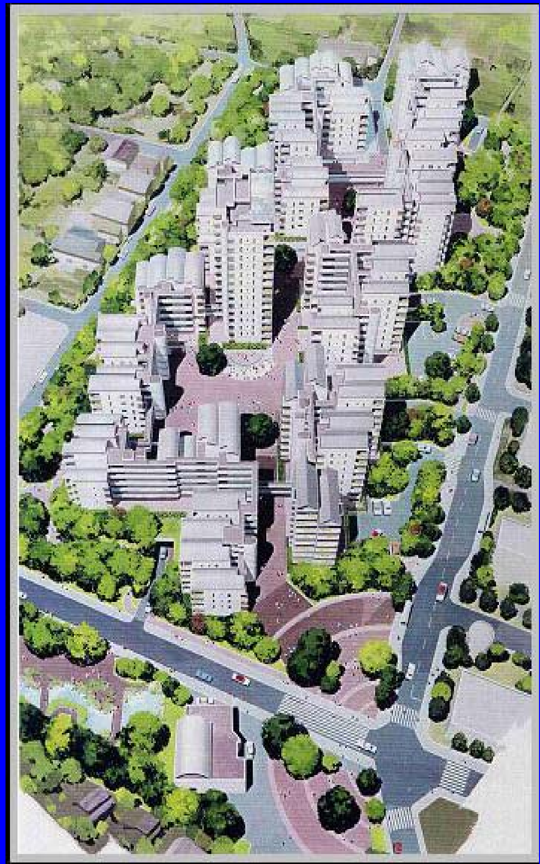



*Overall number of isolated buildings in Italy during years (Summer 2009)*

**There are several applications anti-seismic devices manufactured in Italy in other countries too**

***<u>87.4 m building,</u>* Tokyo (2000): 30 LDRBs + 99 EPDs, T = 4 s; anti-uplift**

***<u>Applause Building,</u>* Osaka, protected by a hybrid control system**



# JAPAN

**(> 5,000 isolated buildings, including over 120 high rise ones)**

***1st r.c. <u>artificial ground</u>, Tokyo: 12,350 m$^2$, supporting 21 6- to 14-storey dwelling buildings, with a parking below; 242 isolators (LDRs, Ball Bearings or BBs, RBs/SDs), T=6.7 s, S=80 cm (super-structure mass = 111,600 t)***



***Retrofit with sub-foundation of the National Western Art Museum (Le Corbusier) And the Gates of Hell, Tokyo (1999)***

**Retrofits began at the end of the years 1990s**


**SI is now also used for about 3,000 private houses, even of small sizes *(e.g. with sphere isolators, coupled with viscous dampers (VDs) and re-centering devices)***

# SOME RECENT APPLICATIONS IN JAPAN

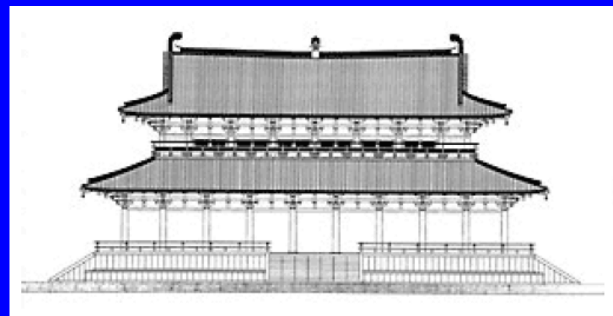
**(ED systems are used in ≈ 1000 buildings and 2000 houses)**

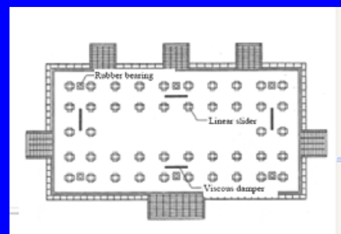
*"Artificial ground"*

*Roof garden (Green Mass Damper or GMD) used as "Tuned-Mass Damper" (TMD)*

*Active dissipation bridge (ADB) between high rise buildings*

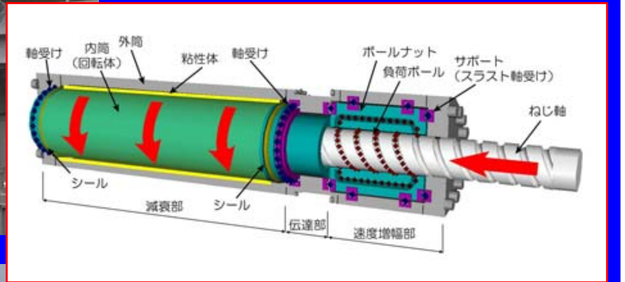
*Factory for the production of semiconductors ($h = 24.23$ m, total area ≈ 27,000 $m^2$), 2006*






*Retrofit with SI of the Daigokuden at Nara, begun in 2007*

# Japan: energy dissipation




↑ *RTD: sphere recirculation viscous damper*

*Telecommunications building (30 storeys), protected by RTD*

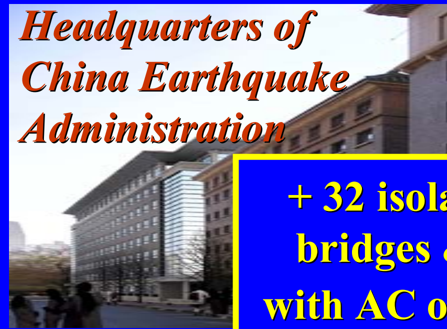
*Seismic retrofit of an existing hospital building by means of RTD (Tokyo)*

*Shantou, 1st Chinese use of HDRBs (1994)*

# P.R. CHINA

Many of the ≈ *690 Chinese isolated buildings* are dwelling and 270 were masonry ones already in June 2005 (mostly new constructions). The annual number of applications doubled after the Wenchuan quake


*The tallest Chinese Building Taiyuan City (Northern China)*



*Headquarters of China Earthquake Administration*

+ 32 isolated bridges & 8 with AC or HC

*4 bldgs. at Beijing ↑ on the same isolated "artificial ground"*

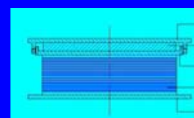
*60 new masonry dwelling buildings (W. China, 1996)*

*Chinese high rise bldg. protected by VDs →*

+ 101 bldgs. with ED or TMD & 5 with AC or HC

*25% saving ⟶ average height increase of 3 storeys (additional 100,000 m²)*

*New Beijing residential centre:* 50 isolated buildings (7-9 storyes, 480,000 m²) on an unique 2-storey sub-structure (1500 m · 2000 m), with all infrastructures



*Buildings above the Beijing Subway Central Station & their 3D isolators (4 = vertical isolator)*

# RUSSIAN FEDERATION
## (≈ 600 isolated buildings)

**(a) Recent retrofits of historical buildings**

*The Irkutsk central bank (Chinese HDRBs)*

*National Drama Theatre at Gorno-Altaisk (HDRBs + Visco-Elastic Dampers or VEDs)*

*State Concert Hall at Grozny (HDRBs)*

*Mihailo-Arkhangelskaya church, Irtutsk (HDRBs)*

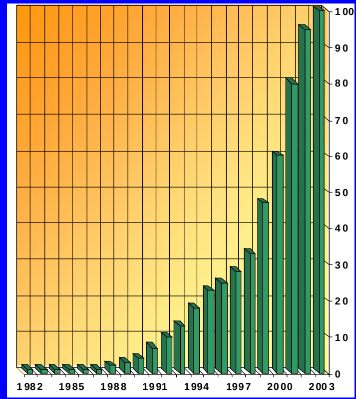
**(b) Projects of new high rise buildings**

***(some with Italian isolators)***

*R.c. 27-storey Sea Plaza Hotel (+ 2 under-ground - h≈93 m, A=40,000 m$^2$), at Sochi, Ordzhoni-kidze Street (102 Italian LRBs)*

*New r.c. residential centre at Sochi, with cinema, underground parking and offices (h≈100 m, A=50,000 m$^2$, 200 LRBs)*

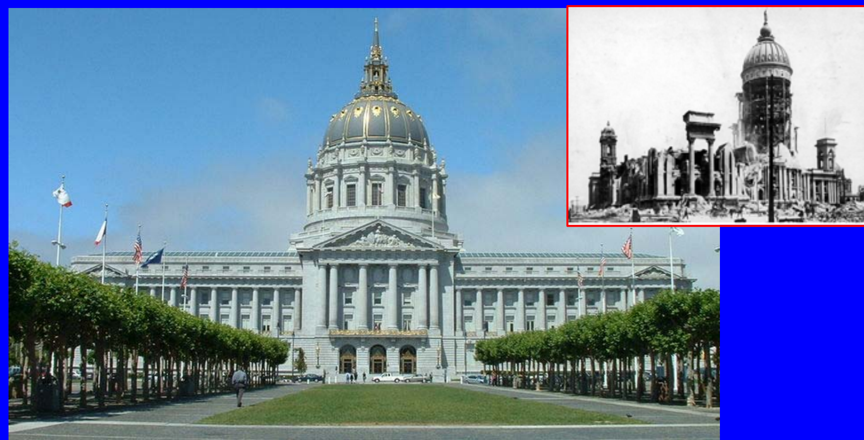
# SEISMIC ISOLATION OF BULDINGS IN THE USA




*Emergency Management Centre at San Francisco (M = 8.3)*

*Asian Art Museum, Golden Gate Park, San Francisco (it replaced the insufficiently safe previous museum, 2005)*

**The US code for isolated buildings is particularly penalizing: the present 100÷ 200 applications mainly concern <u>large public buildings</u>, designed to withstand very large earthquakes**



*San Francisco City Hall, destroyed by the 1906 earthquake, reconstructed in 1912, damaged again by the 1989 Loma Prieta earthquake , retrofitted with 530 LRBs & 62 SDs in 2000 (total cost = 105,000,000 US$)*

**Almost 50% of the U.S. applications of SI concern <u>existing</u> public buildings, many of which historical**

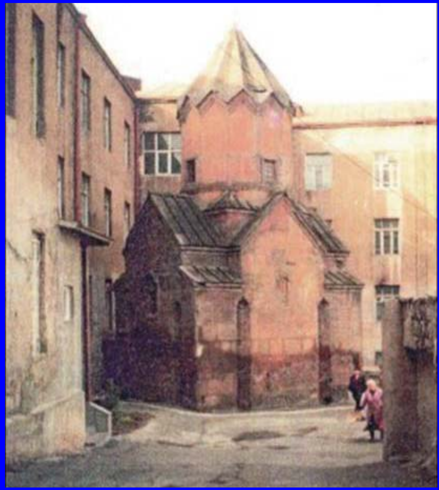
**In addition, 600÷650 isolated bridges & viaducts and ≈ 1·000 buildings protected by ED devices**

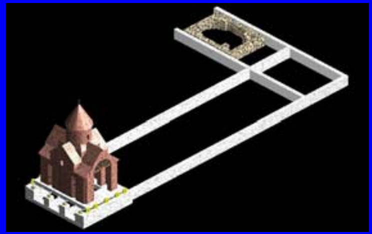
# ARMENIA

**(32 isolated bldgs.)**

*Vanadzor: retrofit, Armenian Medium Damping Neoprene Bearings (MDNBs), 2002*


*10- to 16-storey "Our Yard" multifunctional complex, isolated at Yerevan with IDNBs in 2006 (17- and 20-storey building being erected or designed)*





*St. Cathoghikeh (Yerevan): project of foundations cut and building displacement & SI*

# NEW ZEALAND

**≈30 buildings with SI & ED, several bridges & viaducts**

*Wellington Parliament, built in 1921 (retrofit with LRBs, 1992-93)*

*Te Papa Museum, Wellington*

*Maritime Museum, Wellington (retrofit, 1993)*

**TURKEY**

**Terminal of the Ataturk airport, Istanbul,** ***seismically retrofitted, during construction after the 1999 earthquakes, with 100 FPS devices (1st isolated Turkish bldg.)*** **– Further buildings have been protected with RBs**

**GREECE**

**Onassis Center, Athens: Acropolis Museum** ***during construction with 94 "Sliding Isolation Pedulum" (SIP) devices in 2006*** **- Further buildings, bridges & viaducts have Italian isolators and dampers**

**PORTUGAL**

**"La Luz" Hospital and residence for old people at Lisbon (*315 Italian HBRBs, 2006*) – Italian devices have been used in bridges & viaducts too**

**CIPRUS**

**Shacolas Park commercial center (Nicosia):** ***2 r.c. - steel mixed structure buildings, 164 HDRBs (Italian design, 2006)***

**ROMANIA**

**Design of retrofit with SI of the Victor Slavescu historic building,** ***erected in 1905 (55.2 m x 20.87 m, H=22.5 m)***


**MARTINIQUE (FRANCE)**

***Schools and other public buildings are <u>obligatorily</u> isolated (<u>4 schools</u> had been completed in 2007). NBs + VDs are used***

**MEXICO**

**Legaria secondary <u>school</u> (Mexico City), *isolated by a Mexican rolling system (1st Mexican application, 1974)* – Further 6 isolated structures and 25 buildings with dampers in 2007**

**CHILE**

**Santiago: Comunidad Andalucia, *1st Chilean isolated building (HDRBs, 1992)***

**& Nuevo Hospital Militar La Reina**

***(80,000 m$^2$, 114 HDRBs+50 LRBs, cost=112.8 MUS$, 2005) – US code)***

***Excellent behavior of isolated buildings during the earthquake of February 27, 2010***

**CANADA**

**Golden Ear Bridge *(Italian Curved Sliding Surface – CSS – devices, 2007)* – Several buildings with dampers (BRBs, etc.)**

**INDONESIA**

***Southern Java (HDRBs, 1994) –***

**Italian HDRBs on the Medan City Hall**

## VENEZUELA

← Caracas – Tuy Medio railway: 26 viaducts with isostatic spans ($L_{tot}$=7775 m, 217 spans) protected by Italian devices (1999-2003)

## SOUTH KOREA

← Approaches of the Seo-Hae Granel Bridge (L=5820 m, $H_{pile}$=12-60 m), retrofitted in 2000/2001 with 54 VDs manufactured in Italy

- *13 isolated large LNG tanks at Inchon and Pyeong-Taek*
- *approximately 400 bridges and viaducts protected by SI or ED (partly with Italian devices)*
- *only 1 isolated building, but several high rise buildings with dampers: a rapid is extension foreseen, because of the 2005 Busan-Fukuoka quake (M=7.0) and that (M=4.8) of 2007*

## IRAN

- *Only a few buildings protected by SI and ED have already been completed (1 with Italian ED devices)*
- *A huge ongoing application of SI at Parand, near Tehran, with hundreds of new isolated buildings (but only 5 completed in 2009)*

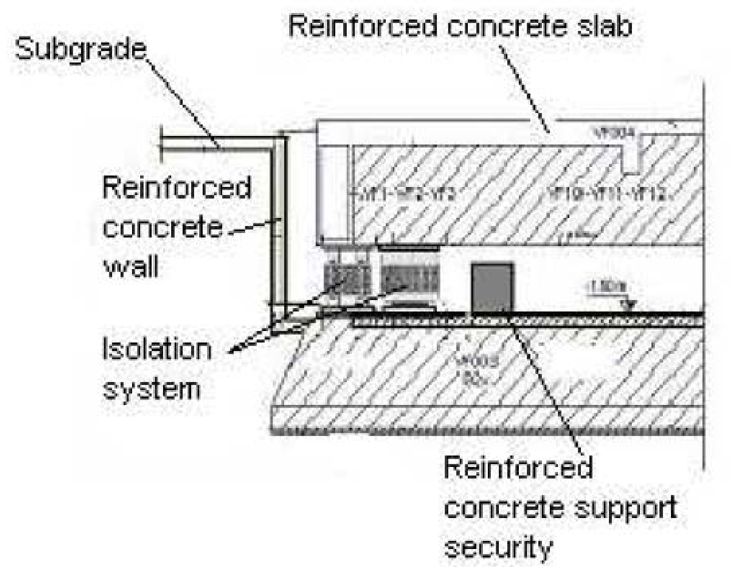
← The Iran Bastan Museum at Tehran, to be retrofitted with SI in the framework of a collaboration between Iran and Italy

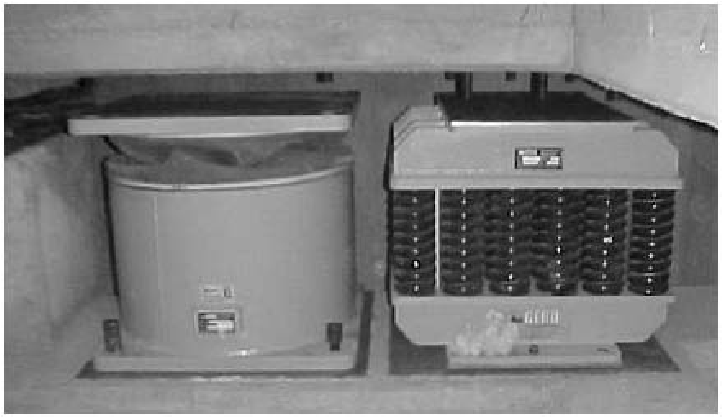
# Isolated buildings in Argentina

*(possible "near fault" earthquakes, with strong vertical components)*

**Isolated buildings in further countries:**

- India;
- Israel;
- ……



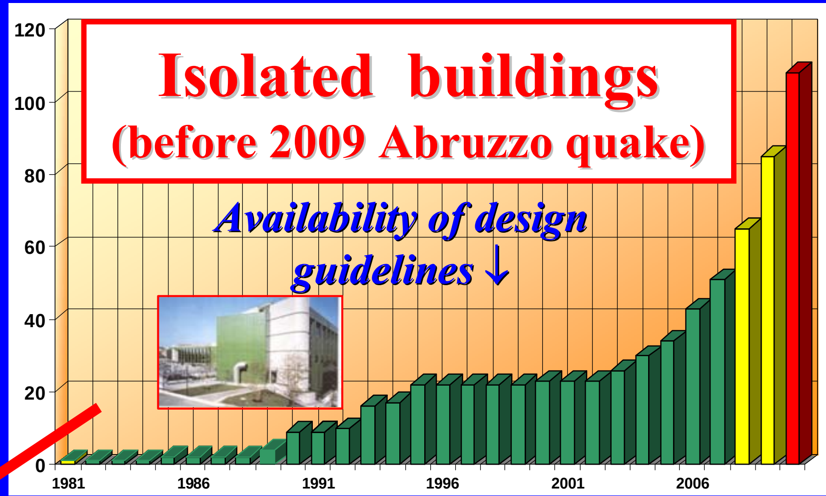
***Dormitory for University students at Mendoza, isolated by means of 4 German 3D isolators (GERB)***

# ITALY



New Fire Station Building, Naples

Somplago Viaduct, Udine-Tarvisio freeway




*Beginning of* ↑ *need for approval*

↑ *OPCM 3274/2003*

*San Giuliano di Puglia (2002):*
*the primary school collapsed* →

← *On-site tests (1990) to $s = 110$ mm ($= 0.8\ s_{design}$)*

**Telecom Italia Regional Center of Marche Region,**
**1st Italian large building application of SI**
*(5 buildings, 8 storeys, h= 25 m, 297 HDRBs, 1991)*

**BEFORE ABRUZZO QUAKE:**

- ≈ 70 isolated buildings
- ≈ tenths with other systems
- > 250 bridges & viaducts

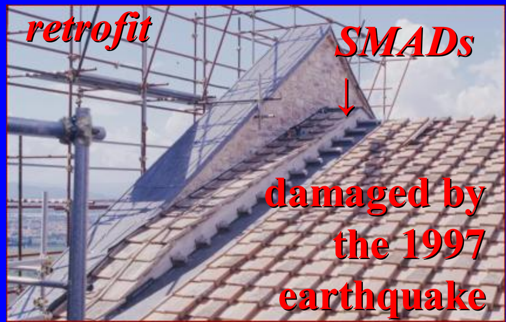
# PRESENT BUILDING SI


University of Basilicata, Potenza (221 HDRBs, 1995)

Gervasutta Hospital, Udine (52 HDRBs, 2005)


Civil Defense Center, Foligno: main building under construction (10 HDRBs, safety certification of A. Martelli)

NATO Center, Southern Naples (399 HDRBs +20 SDs)




Upper Basilica of St. Francis at Assisi (2 · 47 SMADs + 34 STUs, 1999)




Madonna delle Lacrime Sanctuary (11,000 t), Syracuse (EPDs, 2007)

New private house, San Giuliano di Puglia (13 HDRBs + 2 SDs, 2007)

Poly-functional Center, Naples (630 HDRBs, 2005)


House at Fabriano, damaged by the 1997 earth-quake (56 HDRBs, 2006)

# Seismic protect-ion of schools

## *With energy dissipation systems*

*School retrofits with EPDs in Potenza and its province, zone 1: D. Viola (2000) and G. Leopardi (2004)*

*Retrofit with VEDs of the Gentile Fermi school (damaged by the 1997-98 Marche and Umbria earthquake) in Fabriano (Ancona), zone 2 (2000)*

*Costruction of the new Polytechnic University of Marche (r.c. prefabricated structure), Ancona, zone 2 (86 BRBs, 2006)*

**Collapse of the Francesco Jovine school in San Giuliano di Puglia (Oct. 31, 2002)**

***Reconstruction of the school (Autumn 2006 – September 2008) Safety was certified by A. Martelli for ENEA and C. Pasquale on September 2, 2008***


# Seismic isolation of further schools

**5 new schools in Tuscany (zone 2)**

***HDRBs + SDs***

***Morrone sul Sannio (CB), zone 2, 2005-2009***

***LRBs + SDs***


***Bojano (CB), zone 1, 2007-2009***

***HDRBs+SDs***

***Gallicano (LU), completed in September 2009***

- ***LRBs+SDs***

***Mulazzo (MS), structures com-pleted in 2008***

- 

***Romita High School, Campobasso (1300 students), zone 2 (demolition & reconstruction is beginning)***

- ***HDRBs+SDs***

***Marzabotto (BO), zone 3, under constr. since 2008***

- **Safety certified by A. Martelli**

# **Main building (operating room) of the new Civil Defense Centre in Foligno**

***(opened to activity on February 12, 2010, safety certification of A. Martelli)***

*Views in 2009 (Note the architecture)*








**The new Faculty of Letters, Philosophy and Training Sciences of L'Aquila University, formed by 4 buildings supported by an unique slab protected by 77 HDRBs and 34 SDs. The previous buildings were demolished, being unsafe** ***(photos of prof. Antonello Salvatori, University of L'Aquila)***

# The 4 new seismically isolated buildings erected in Cerignola

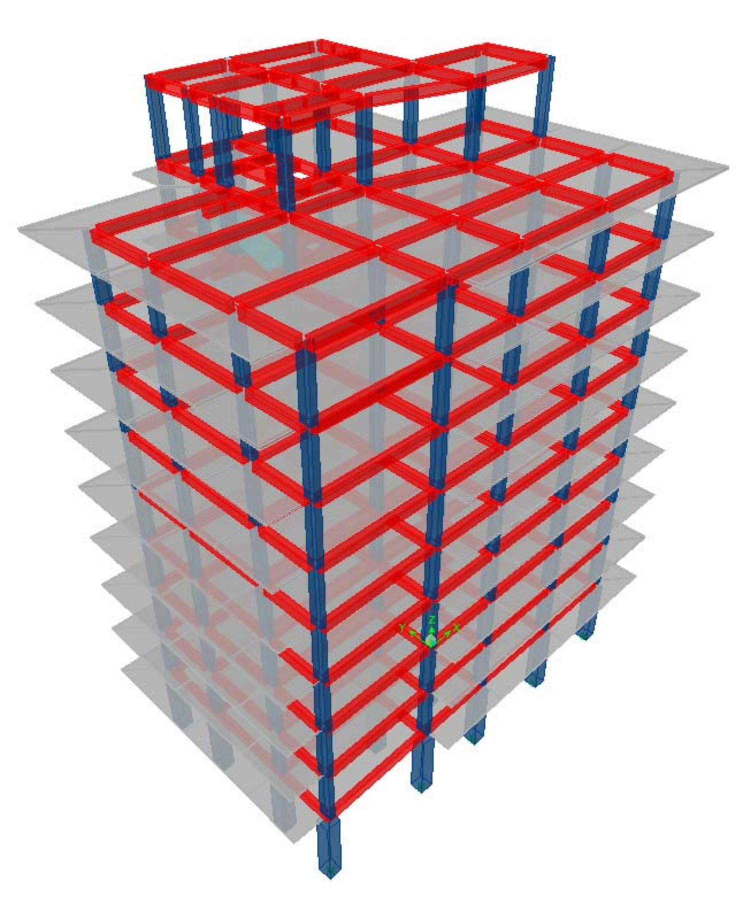
*(September 2008, with ready structures)*




*However, the safety certificate was signed by A. Martelli only in May 2009, due to delays in the installation of flexible joints for the gas pipes*

**New 8-storey isolated residential building under construction in Messina**

***(seismic zone 1, LRBs + SDs)***




**ABRUZZO EARTHQUAKE OF APRIL 6, 2009**

**L’Aquila, Prefecture**

**ABRUZZO EARTHQUAKE OF APRIL 6, 2009**
**L'Aquila, Santa Maria Paganica Church**

L'Aquila, San Salvatore Hospital (April 2009)

**L'Aquila, San Salvatore Hospital (April 2009)**

**L'Aquila, ANAS Offices (April 2009)** ***(it might be retrofitted with SI)***

# L’Aquila, private buildings (April 2009)

# SI OF PRE-CAST DWELLING BUILDINGS AT L'AQUILA

**C.A.S.E. Project: one of the over 180 seismically isolated platforms erected at L'Aquila, each aimed at sustaining a precast building, for the approximately 17,000 homeless people, made of r.c., wood or steel (June 2009) →**

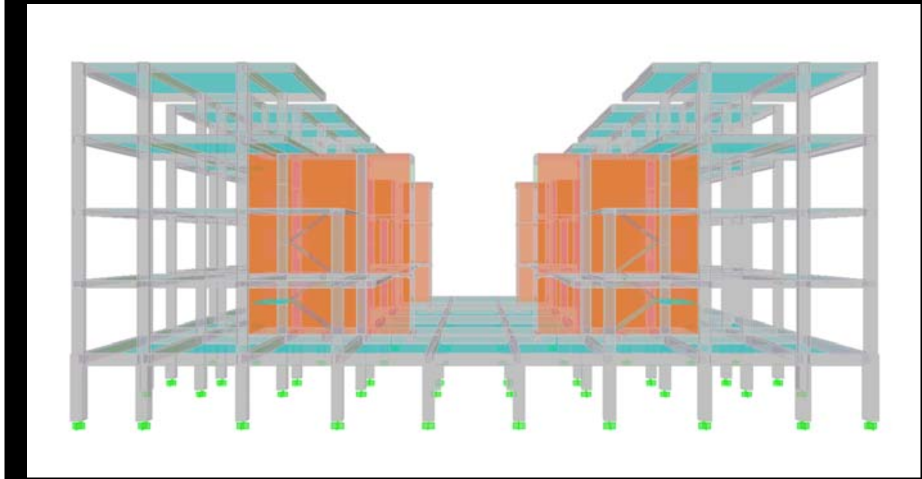
***Two of the 40 curved surface sliding (CSS) isolators manufactured in Italy installed at the top of the piles sustaining each platform***

# C.A.S.E. Project (L'Aquila): double CSS isolators

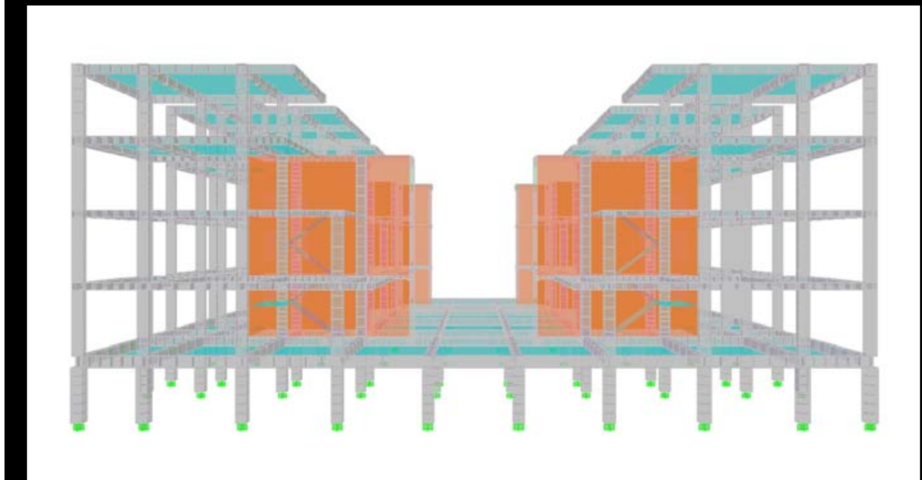
*(with inner rubber protection from dust and humidity)*


*New applications of this kind have been planned in Abruzzo*

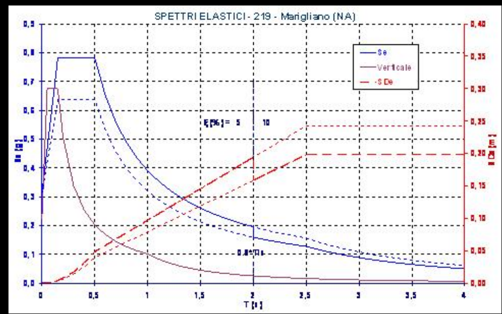
**First European application of seismic rehabilitation with isolation and sub-foundation: the apartment house in Fabriano, damaged by the 1997-98 Marche and Umbria earthquake (20% savings of construction costs with respect to conventional retrofit)**

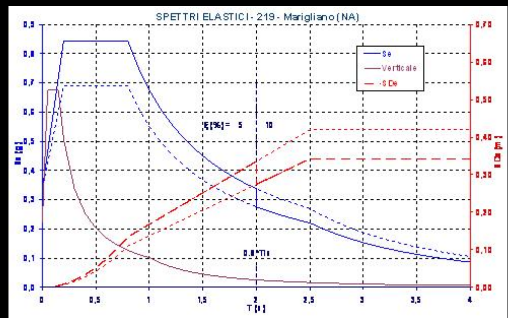


**New buildings, if they were fixed base (T=0.37 s)**



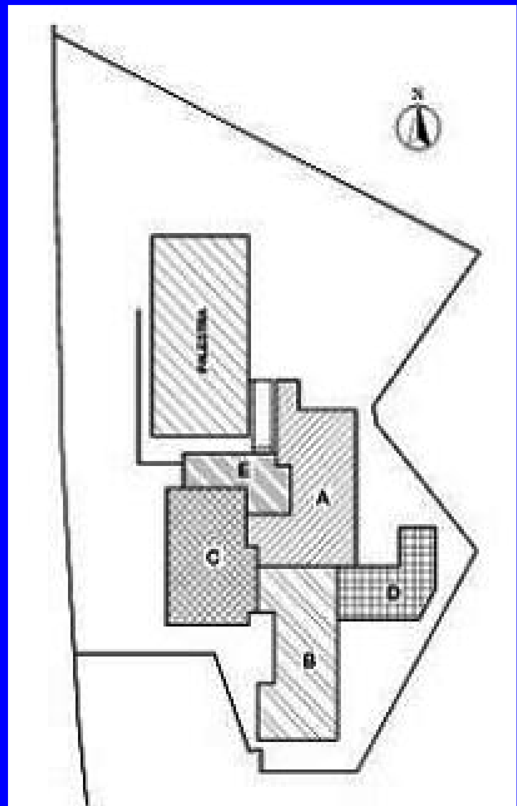
**Group of 6 buildings isolated at the base of one of the 16 support slabs with 40 HDRBs (Φ=500 mm) and 30 SDs (T=2.55 s)**




# *Reconstruction, with seismic isolation, of the "219 complex" of Marigliano (NA)*

***Romita High School***
***at Campobasso,***
***1550 students***
***(present seismic zone 2),***
***for which even***
***static problems***
***were detected by ENEA***
***after the 2002 Molise***
***& Puglia earthquake***





**← Specimen before and after rupture (minimum resistance = 46 kg/cm$^2$)**

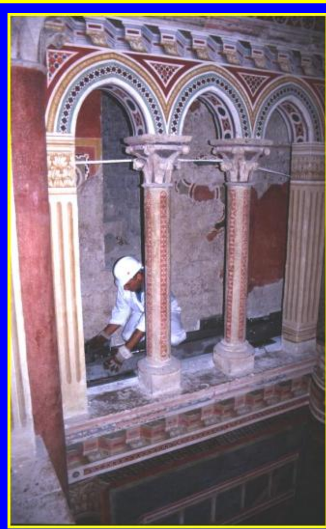
**However, it was only statically reinforced**

**Only now, as a consequence of the 2009 Abruzzo earthquake, it was decided to partly demolish and reconstruct it with SI**

# SEISMIC PROTECTION OF CULTURAL HERITAGE







*Installation of the 47 SMADs* (1999) *Installation of the 34 STUs (1999)*

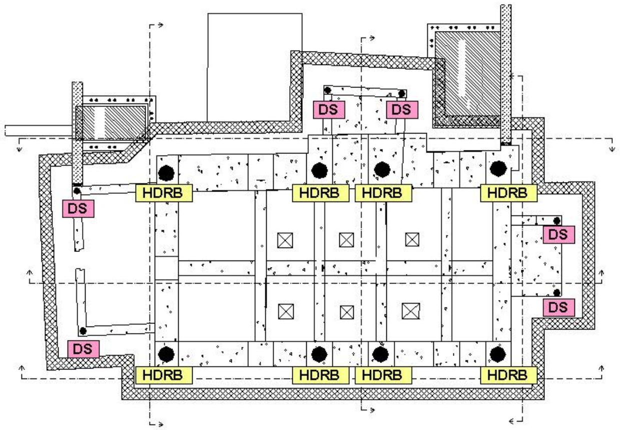
***← Upper Basilica of St. Francis at Assisi, damaged by the 1997 earthquake:***
**SMADs & STUs**
**developed with the collaboration of ENEA (1999)**



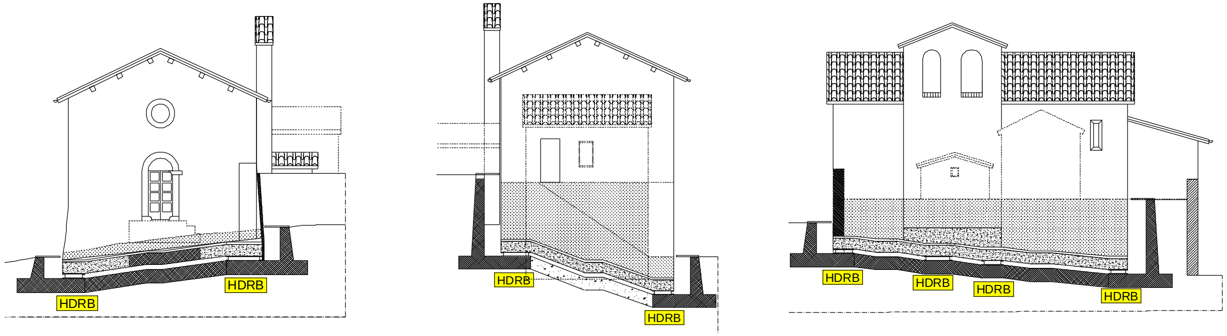


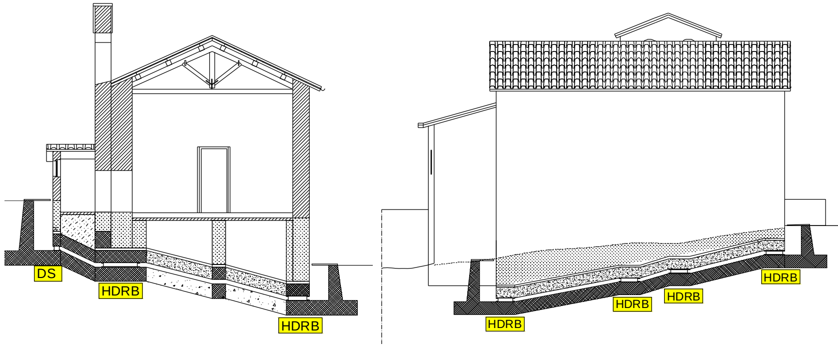
***San Giovanni Battista, Apagni (PG), damaged by the 1997 quake, after its conventional retrofit (approved design)***

**and SEISMIC ISOLATION**



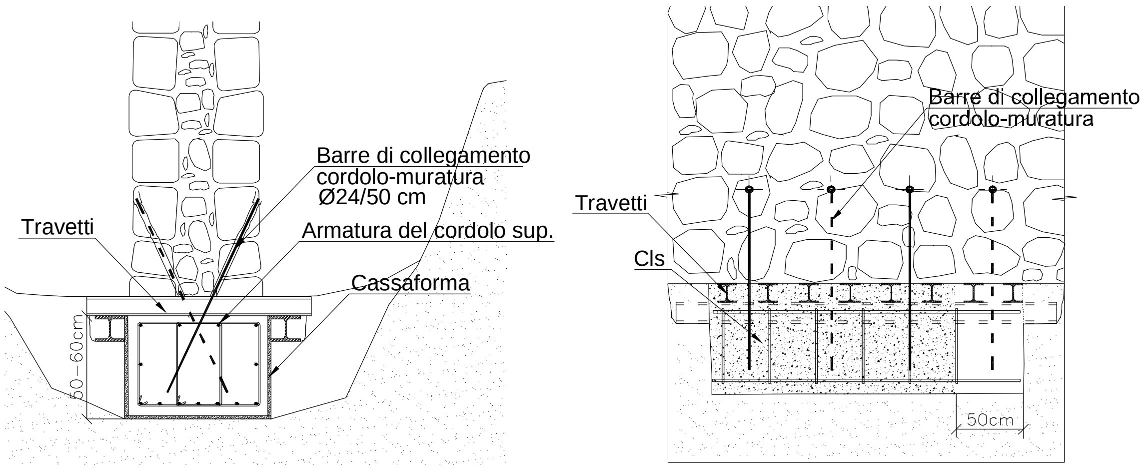

*Plan of the sub-foundation beams and location of the 8 HDRBs and 6 SDs*



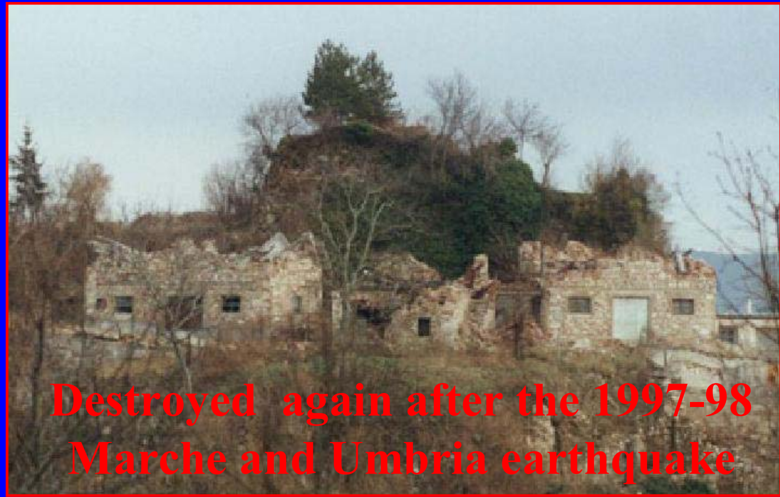




*Assumption for the construction of the subfoundation*

# Design of the sub-foundation and SI system of the San Giovanni Battista Church at Apagni




*Excavation for the construction of the sub-foundation structure and steel reiforcement*

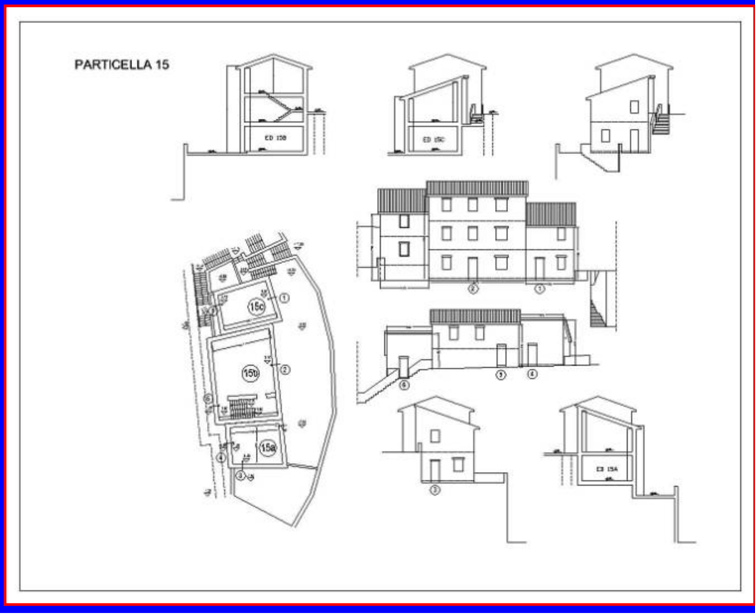




**Reconstruction of ancient masonry villages by means of SI**

**Mevale di Visso (Macerata)**

***<u>Demolished in 2001–2002</u>***

**← Local amplification to 2.4 (also due to meters of debries)**

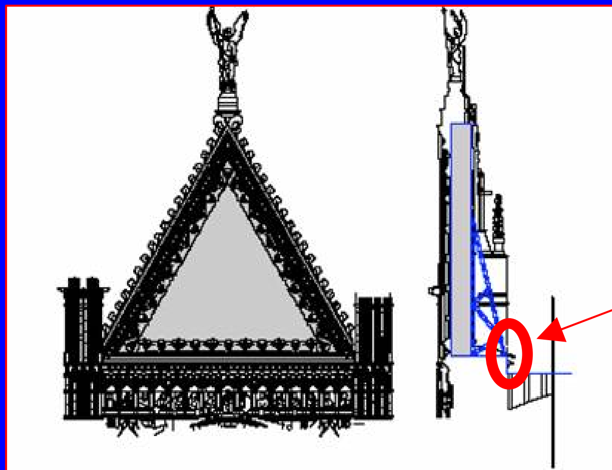



***← Reconstruction with SI (HDRBs) and the ortiginal methods and materials was decided by the TSC of Marche Region, based on the results of a feasibility study carried out by ENEA***

**(<u>additional cost</u> = 9 % with respect to the non-reinforced masonry; =10.5% with respect to r.c.)**

# DAMPERS

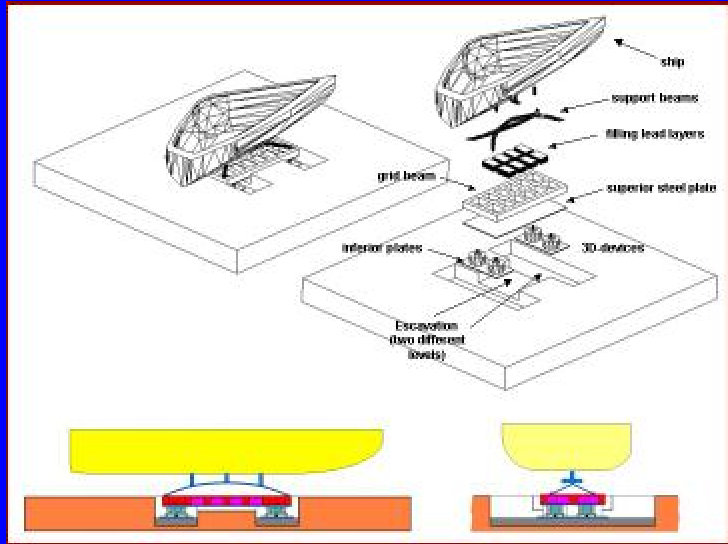
*Seismic improvement, with EPDs on the roof, of the Cathedral of Santa Maria di Collemaggio of L'Aquila, an unique example of Abruzzo Romanic style (almost destroyed by a strong earthquake, reconstructed in Baroque style and restituted to the original style some years ago, which vibrated during the 1997-98 Marche and Umbria earthquake)*




*Seismic improvement of the Dome of Siena, performed with re-centering VDs to avoid the overturning of the façade*

# Cathedral of S. Maria di Collemaggio, L'Aquila, after the Abruzzo quake




***<u>Horizontal SI</u>:***
***3 steel spheres between 2 steel plates + rubber re-centering cylinder;***

***<u>Vertical SI:</u>***
***spring + VD***

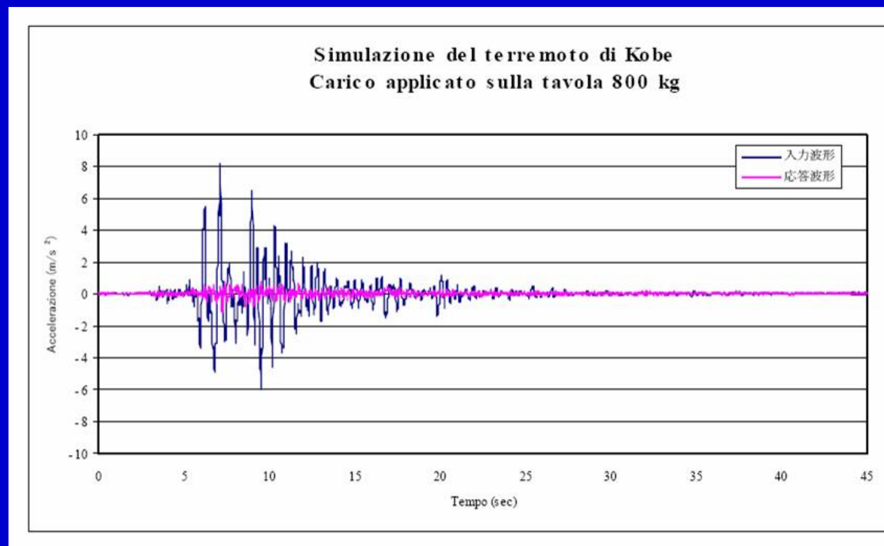
**Wooden Roman ship excavated at Ercolano (Ercolano Museum, Naples)**

*Sketch of its supporting and protection system (resently installed), a 3D SI device and characterization of the 3D SI system through shake table tests (SPACE project)*

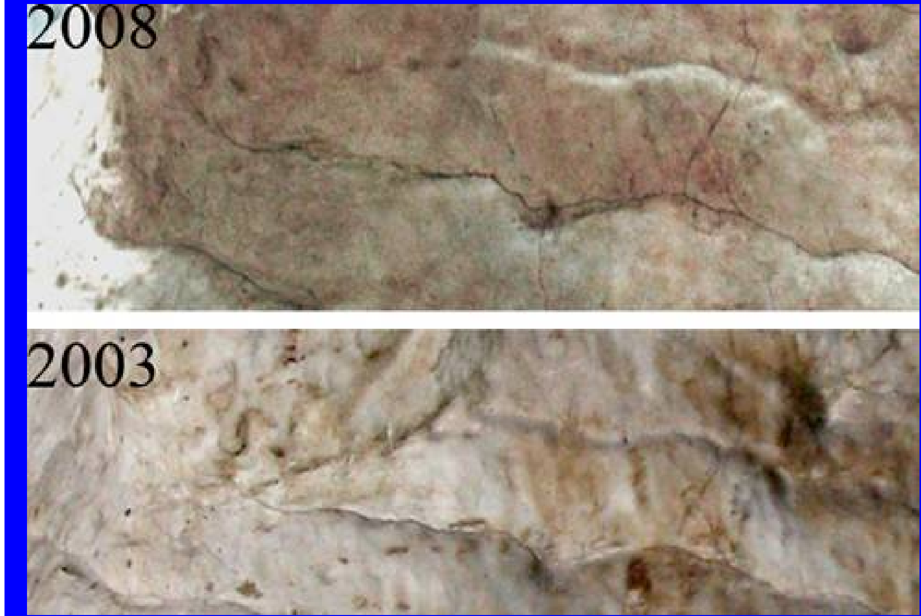
# Seismic protection of museum objects, computers and other valuable vulnerable objects

***Anti-seismic tables with Japanese sphere recirculation isolators***

**Experimental tests**

# 2009 G8 Summit 2009 at L'Aquila:
# Japanese sliding table with sphere recirculation isolators protecting the statue of the "Capestrano Warrior"





**Evolution of fissures in the ankles of David of Michelangelo**

**Museum of L'Aquila: statues destroyed by the earthquake of April 6, 2009**

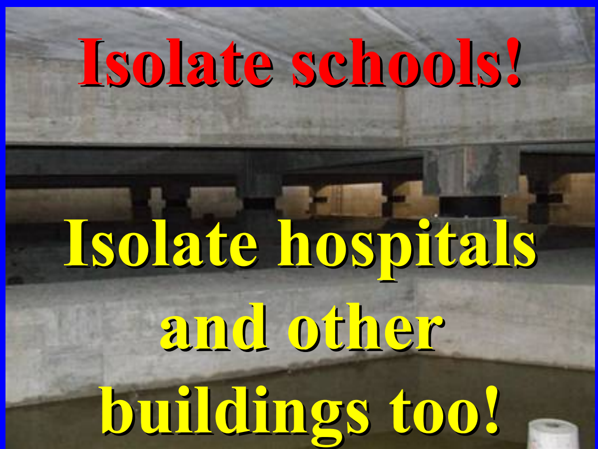
***Let's try to avoid this for David!***

# WHAT WE DO NOT WANT TO SEE ANY MORE:

October 31, 2002: *27 children die due to the collapse of the F. Jovine primary school at San Giuliano di Puglia (Italy)*

May 12, 2008: *900 students die due to the collapse of a secondary school at Dujiangyan (P.R. China), during the Wenchuan earthquake*

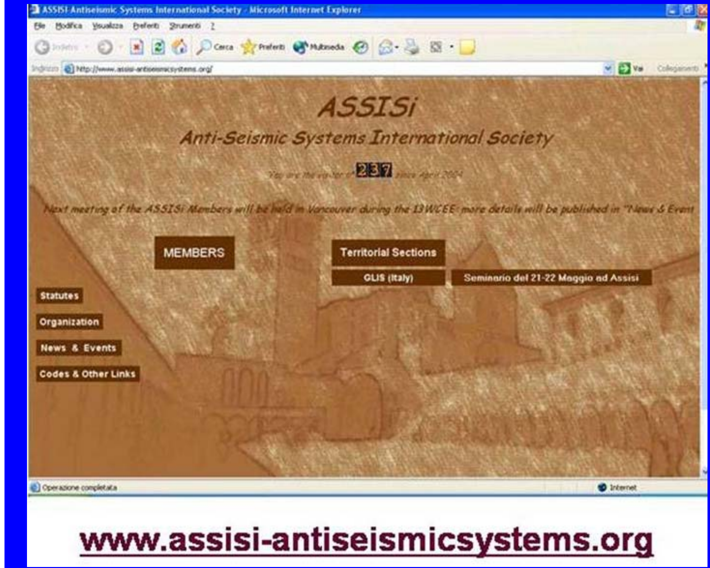
April 5, 2009: *numerous buildings collapse or are severely damaged by the Abruzzo earthquake (Italy)*

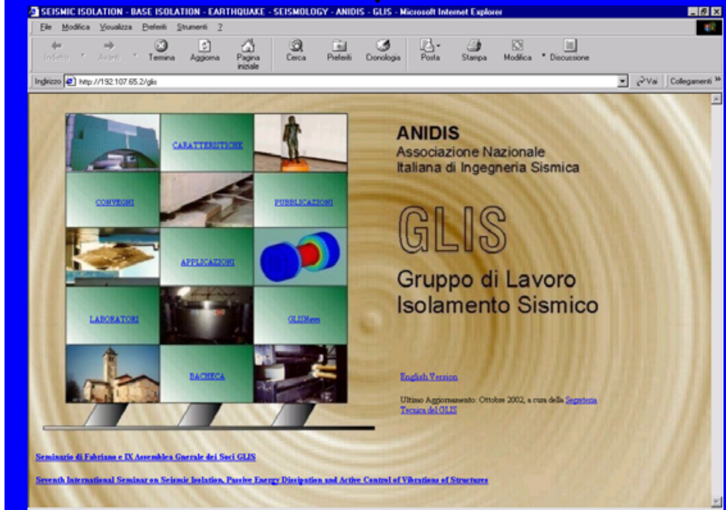


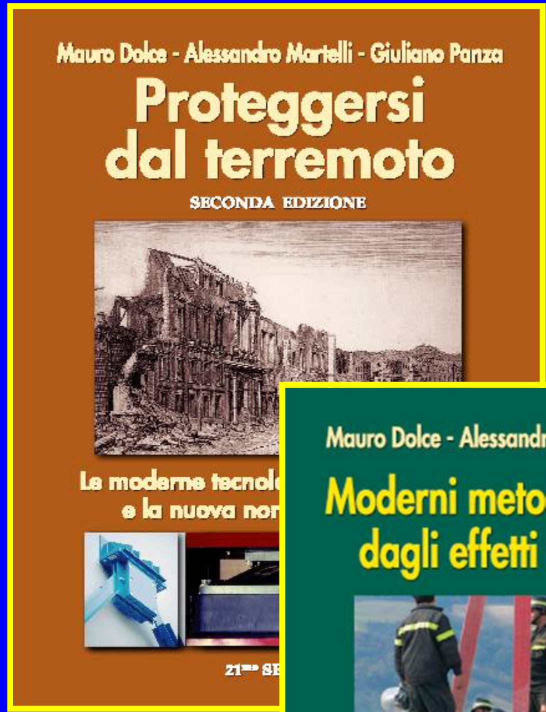


**↑ HOW? ↑**

*Reconstruction of the F. Jovine school with SI (2006-2008)*
*(safety certified by A. Martelli & C. Pasquale on* September 2, 2008*)*






***Thank you very much for your attention***

***The new Italian GLIS association ("Isolation and other Anti-Seismic Design Strategies") was founded in November 2006***