COST C26

Urban Habitat Constructions under Catastrophic Events
EARTHQUAKE RESISTANCE
WG 2 Session, March 30th

Innovative materials and technologies for existing and new buildings in seismic areas

General Report by:

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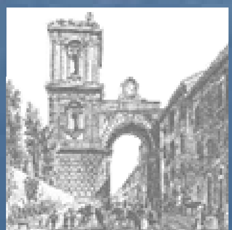
Second University of Naples – Italy



Workshop in Prague, 30-31 March 2007

ACKNOWLEDGEMENTS

The subjects dealt with in this presentation represent major topics of the Research Project PROHITECH “Earthquake Protection of Historical Buildings by Reversible Mixed Technologies” (2004-07) (www.prohitech.com), supported by European Commission within FP6, in which 16 Academic Institutions of 12 European and Mediterranean Countries are involved under the coordination of Prof. F.M. Mazzolani, University Federico II, Naples.

The author gratefully acknowledges the great effort made by all Prohitech Partners and by Prof. Mazzolani himself in facing a so wide research field and in producing a state-of-art advance which was a highly valuable reference for the preparation of this paper.

WHAT MEANS "CATASTROPHIC SEISMIC EVENTS"?

- Earthquake of exceptional intensity;
- Earthquake occurring in a no-seismic area;
- Earthquake striking a building designed without complying with seismic regulation;
- Earthquake striking a degraded/damaged building;
- Earthquake striking a historical or monumental building;
- ....
- .... any other unpredictable event.

BASIS OF THE USE OF "SPECIAL" SOLUTIONS IN SEISMIC DESIGN

- Need for very high performance under seismic action;
- Necessity to comply with severe regulations;
- Optimisation of the structural behaviour;
- Improvement of the structural response under exceptional loading conditions (increase of the structural robustness).

COST C12
WG2 Structural Integrity under Exceptional Actions
(Chair F.M. Mazzolani)

ABOUT THE ROBUSTNESS-BASED SEISMIC DESIGN APPROACH

The most important aspect of a “robustness” approach to seismic design is that, at least in principle, the predictable robustness demand can be entrusted to the seismic protection system, only.

The following advantages would be achievable over the conventional design approach:

- The seismic protection system could be adjusted in order to be tailored to specific robustness-based design requirements;
- If necessary, the seismic protection system can be upgraded and/or updated over time;
- In case of catastrophic earthquake, the seismic protection system can be more easily repaired and/or substituted than the structure;

MAIN REQUISITES OF THE SYSTEM PROTECTION SYSTEM

- Lightness;
- Reliability;
- Ease of monitoring, inspection and maintenance;
- No-added stiffness;
- Ease of substitution;
- Reversibility;

These features involve advanced strategies to be followed, consisting of:

1. Use of innovative materials;
2. Use of seismic control techniques.

WHY INNOVATIVE AND ADVANCED SOLUTIONS?

1. They are able to satisfy not only specific structural or functional needs, but can also improve the global performance of the construction, intended in general terms of reliability, ease of inspection, maintenance, monitoring and long-term durability;
2. In most cases, they are intended to combine the best features of different materials and devices in order to achieve an optimised performance from all points of view;
3. Facing severe earthquakes may require special provisions that go beyond the range of conventional techniques.

Innovative materials

- Special Metal Materials;
- Fibre Reinforced Polymers (FRP);

Basic purposes:

- Use of materials with special properties in order to meet special design requirements and achieve the best performance;
- Creation of light structural elements, in order to optimize the dynamic behaviour;
- Exploitation of material features in the most convenient and effective way (exploitation of the 4th dimension);
- Creation of special devices for the reduction of the seismic structural response;

INNOVATIVE MATERIALS AND ADVANCED STRENGTHENING

1. Exploitation of material features in the most convenient and effective way;
2. Correction of some inherent lacks of existing design and materials;
3. Ease of inspection, maintenance and substitution (reversibility);
4. Use of materials with different properties in order to achieve a performance optimization (“mixed” approach).

COST C12
WG1 Mixed Building Technology
(Chair C. Schaur)

INNOVATIVE METAL MATERIALS

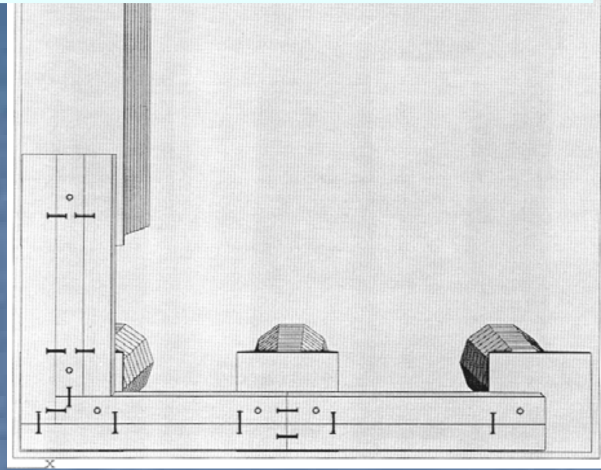
Material:

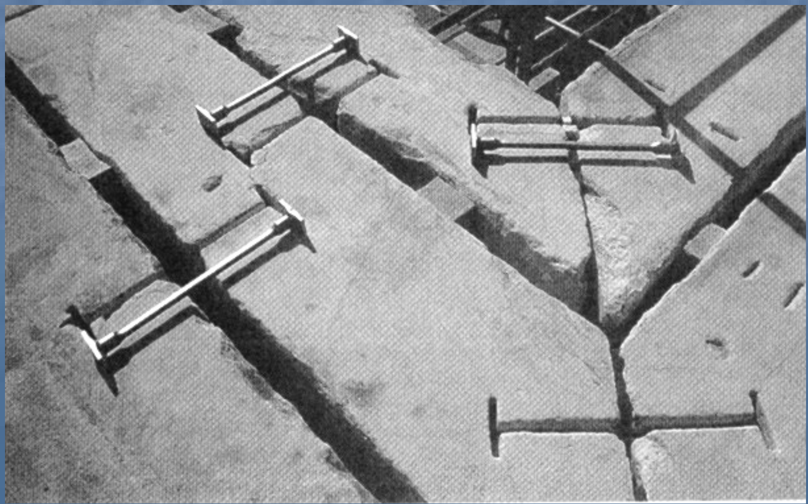
- Stainless steel
- Aluminium alloys
- Titanium alloys
- Shape memory alloys

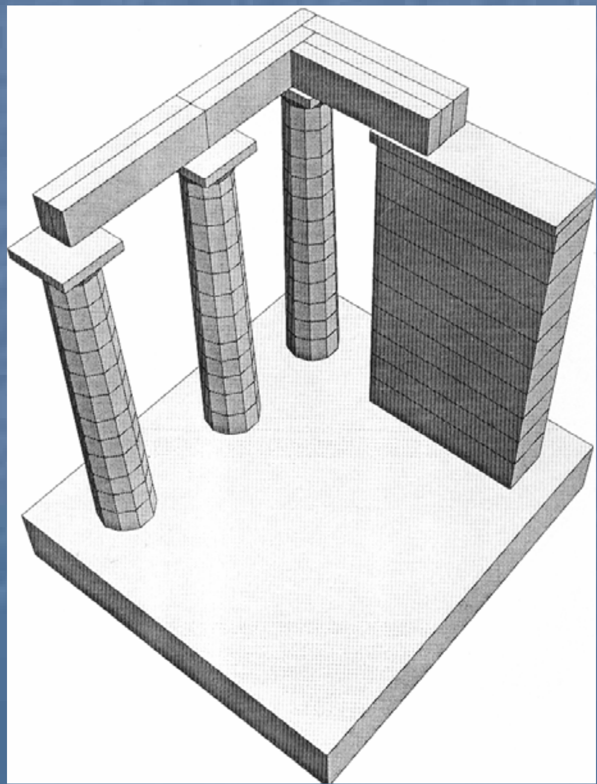
Features:

- High strength-to-weight ratio
- Good ductility
- Product availability
- Ease of installation
- Low maintenance cost
- Reversibility

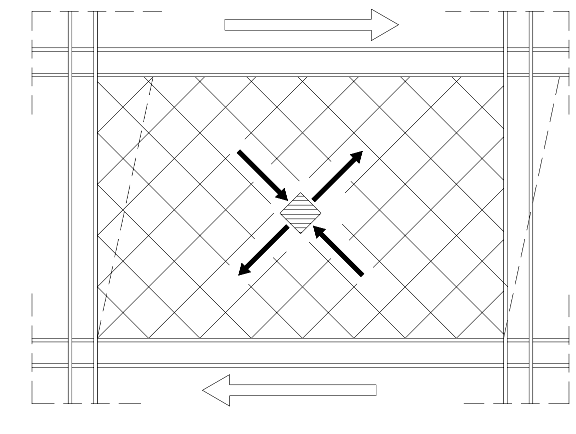
TITANIUM ALLOYS

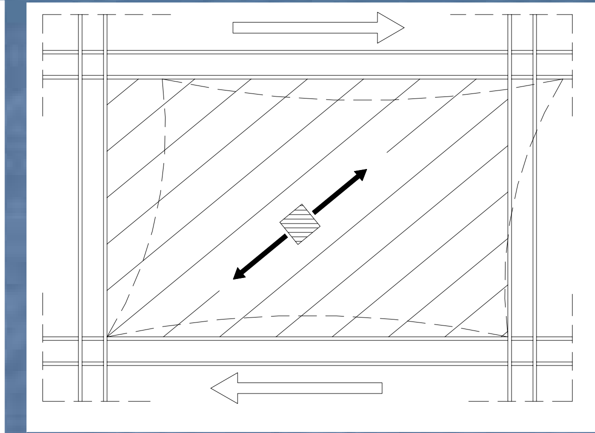


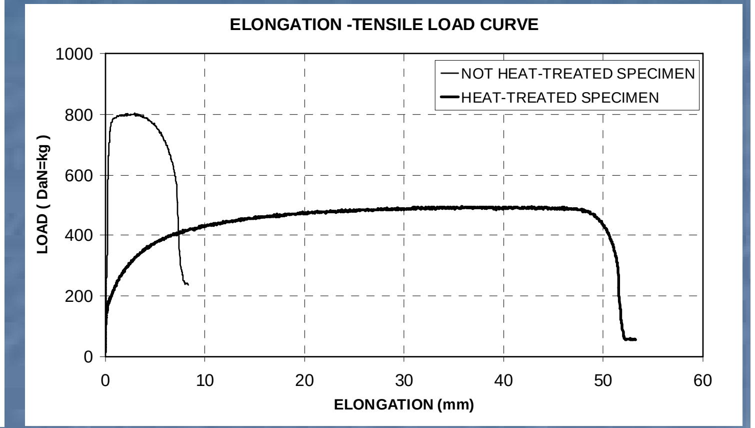


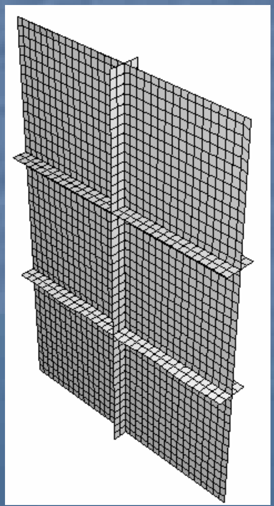


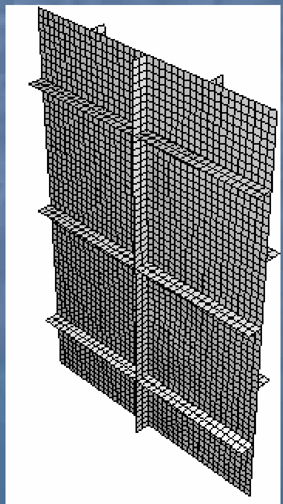
ALUMINIUM SHEAR PANELS

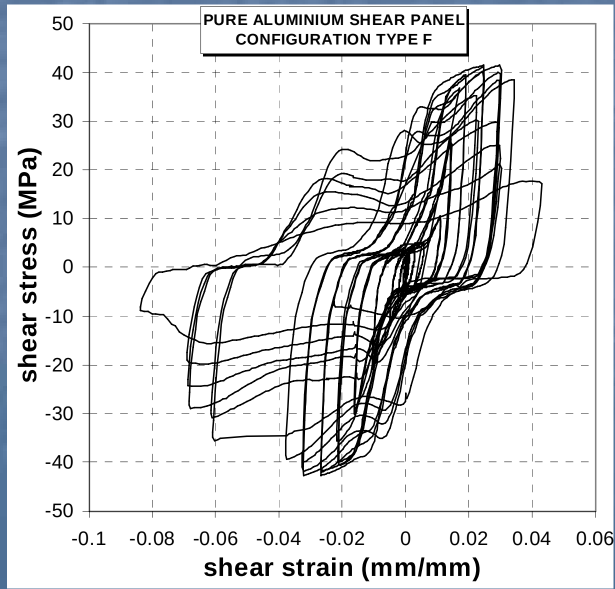




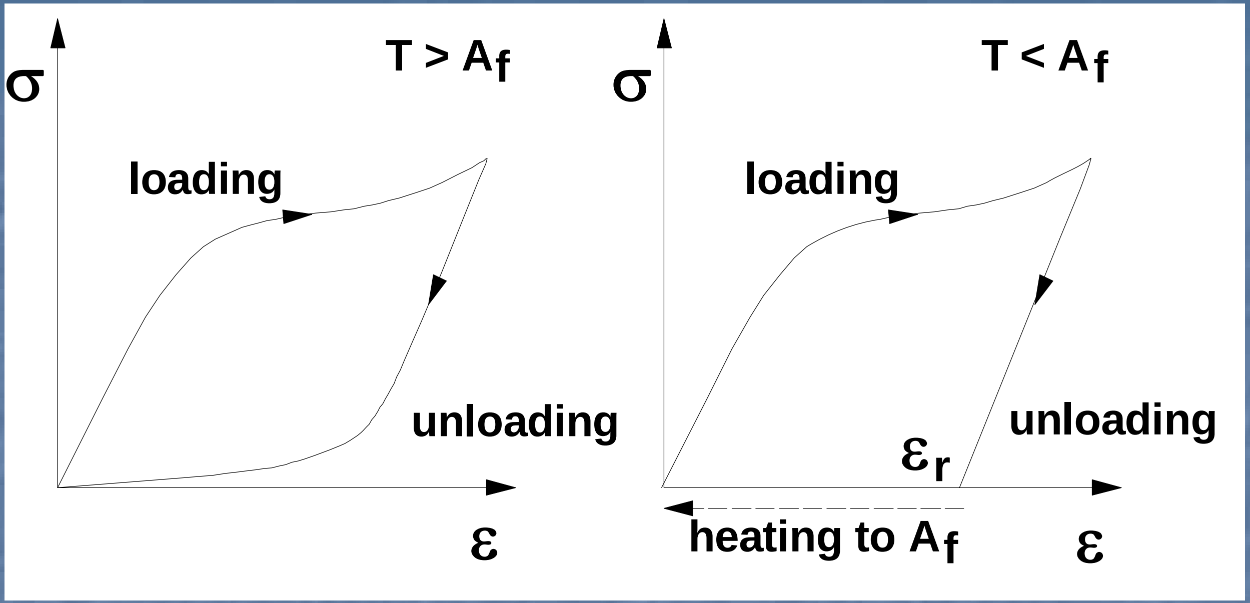


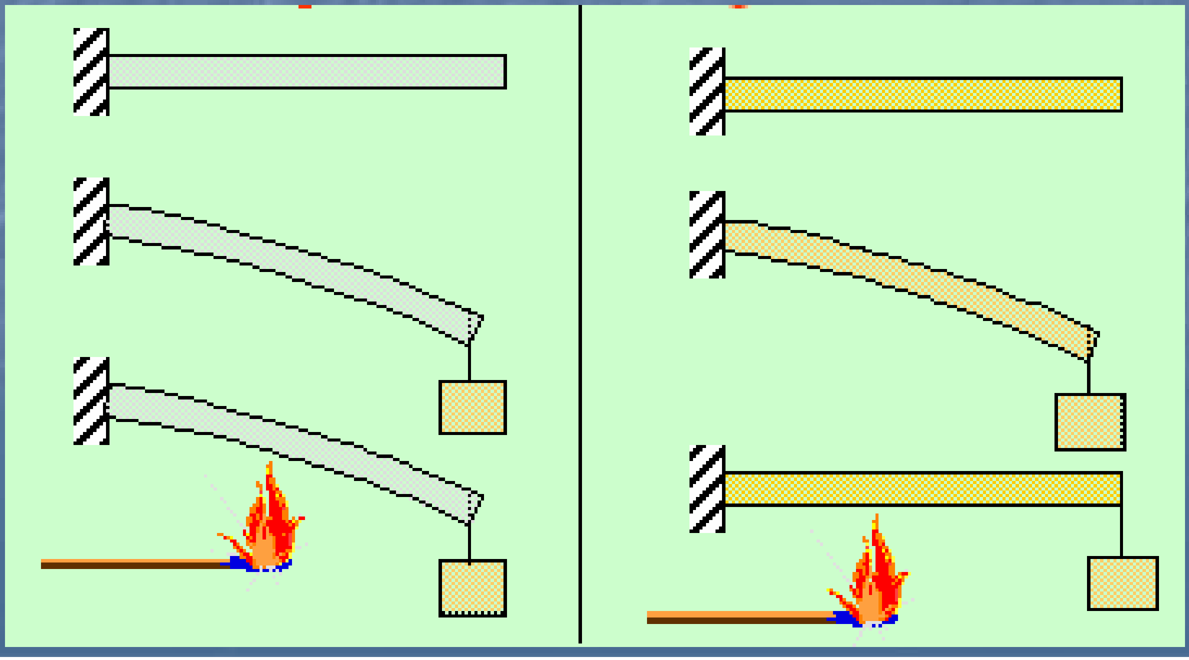






SHAPE MEMORY ALLOYS (SMA)





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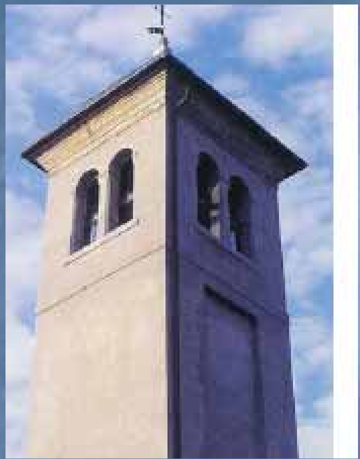
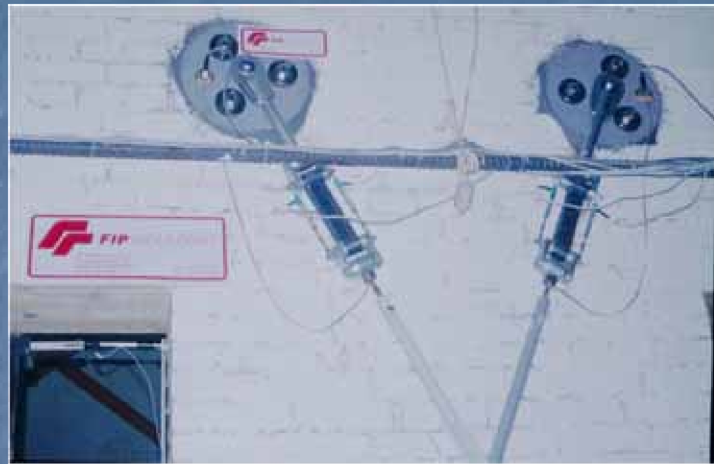




INNOVATIVE FIBRE-REINFORCED MATERIALS

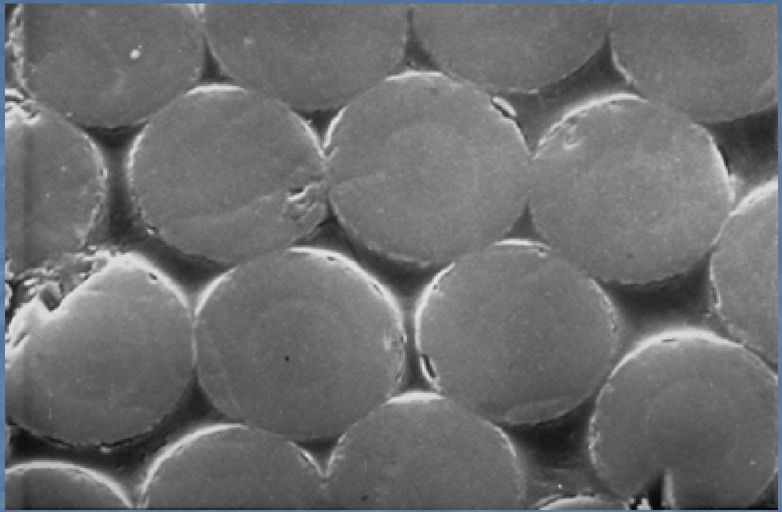
Material:

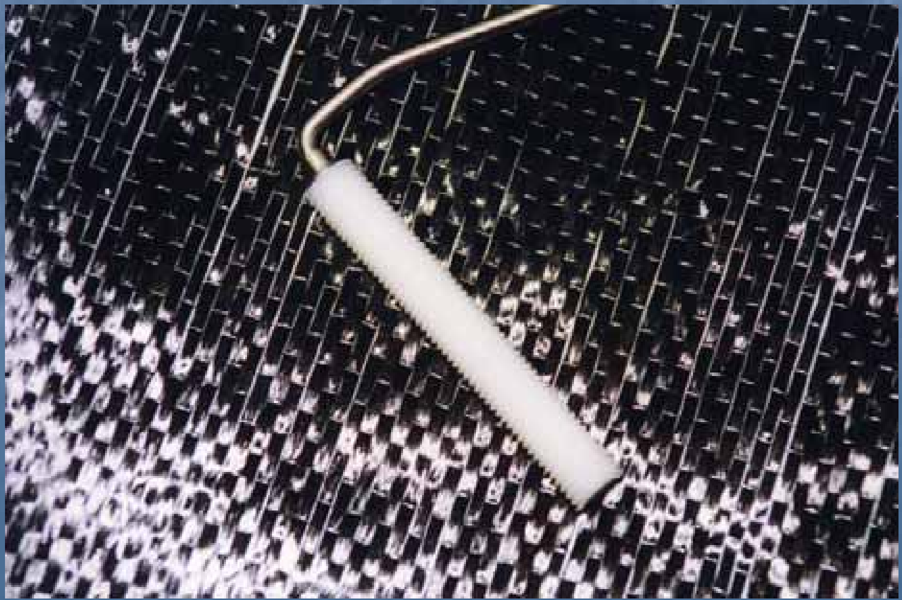
- Carbon fibre polymers
- Glass fibre polymers
- Aramidic fibre polymers

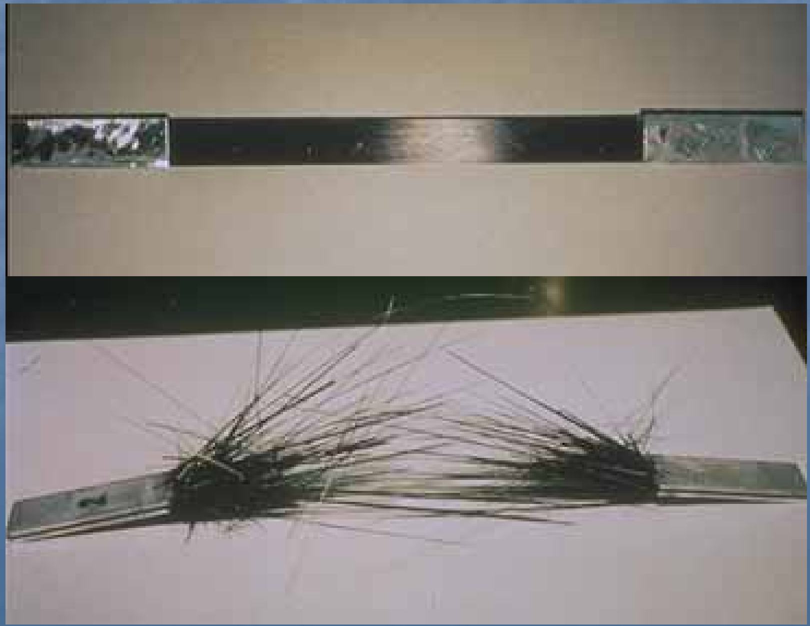
Features:

- Very high strength and stiffness
- Wide range of mechanical properties
- No added weight
- Product availability
- Ease of installation
- No maintenance cost

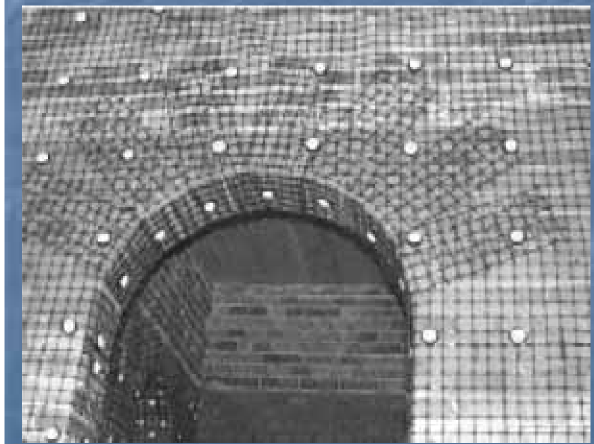
FIBRE-REINFORCED MATERIALS (Courtesy SIKA)







FIBRE-REINFORCED MATERIALS



APPLICATION OF FIBRE-REINFORCED STRIPS (Courtesy SIKA)

USE OF FIBRE-REINFORCED STRIPS

USE OF FIBRE-REINFORCED WRAPPING

USE OF FIBRE-REINFORCED RIGID BARS

Synopsis of mechanical features of innovative metal materials

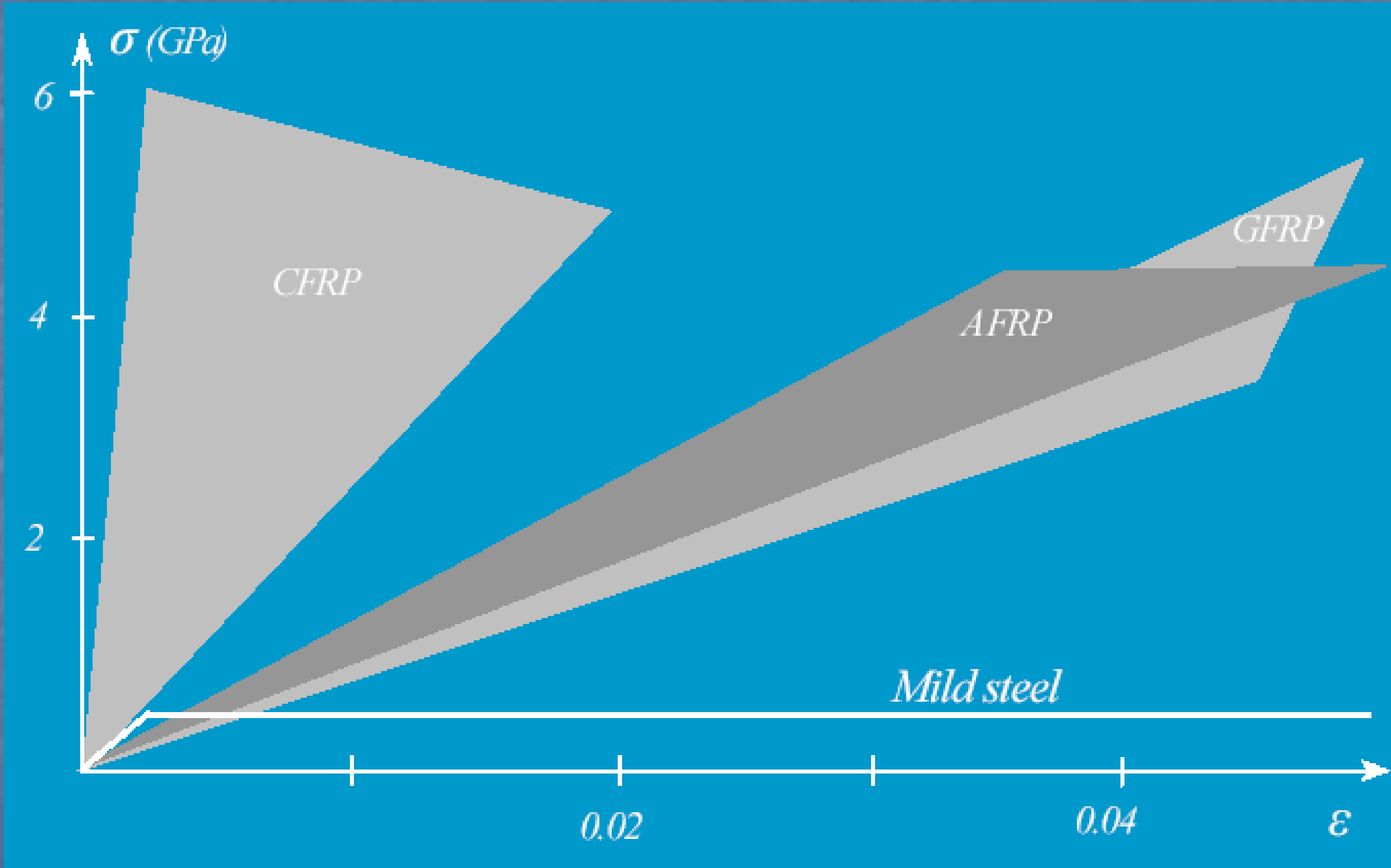
MATERIAL	γ (g/cm^3)	E (kN/mm^2)	$f_{0.2}$ (N/mm^2)	f_t (N/mm^2)	$\varepsilon_t \times 100$ (A_5)	$\alpha \times 10^6$ (C°$^{-1}$)
Mild steel	7.85	206	235 ÷ 365	360 ÷ 510	10 ÷ 28	12 ÷ 15
Stainless steel	≈ 7.8	≈196	200 ÷ 650	400 ÷ 1000	10 ÷ 40	17 ÷ 19
Aluminium alloys	≈ 2.7	65 ÷ 73	20 ÷ 360	50 ÷ 410	2 ÷ 30	24 ÷25
Titanium alloys	≈ 4.5	≈ 106	200 ÷ 1000	300 ÷ 1100	8 ÷ 30	6 ÷ 7
SMA Ni-Ti (Nitinol)	≈ 6.5	28 ÷ 75(*)	100 ÷ 560(*)	750÷960(*)	15.5	6.6 ÷11(*)

(*) Values referred to martensite and austenite, respectively.

Tensile characteristics of fibres (CEB-FIP 2001)

Fibre Type	*Elasticity Modulus (GPa)*	*Ultimate Strength (MPa)*	*Ultimate Deformation (%)*
Carbon			
High Strength	215 – 235	3500 - 4800	1.4 - 2.0
Very High Strength	215 – 235	3500 - 6000	1.5 - 2.3
High Elastic Modulus	350 – 500	2500 - 3100	0.5 - 0.9
Very High Elastic Modulus	500 – 700	2100 - 2400	0.2 - 0.4
Glass			
Glass E	70	1900 - 3000	3.0 - 4.5
Glass S	85 – 90	3500 - 4800	4.5 - 5.5
Aramid			
Current	70 – 80	3500 - 4100	4.3 - 5.0
High Performance	115 – 130	3500 - 4000	2.5 - 3.5

COMPARISON OF MECHANICAL FEATURES OF SPECIAL MATERIALS



BASIC PURPOSES OF SEISMIC CONTROL TECHNIQUES

- Increase of the structural damping, in order to reduce the structural response under seismic action;
- Reduction of the seismic input energy, in order to prevent structural damage;
- Reduction of the inertia forces, in order to reduce the structural response at a given frequency of the dynamic excitation;

STRUCTURAL CONTROL – General considerations

Passive Control Strategies

PASSIVE DEVICES
Non-controllable
No power required

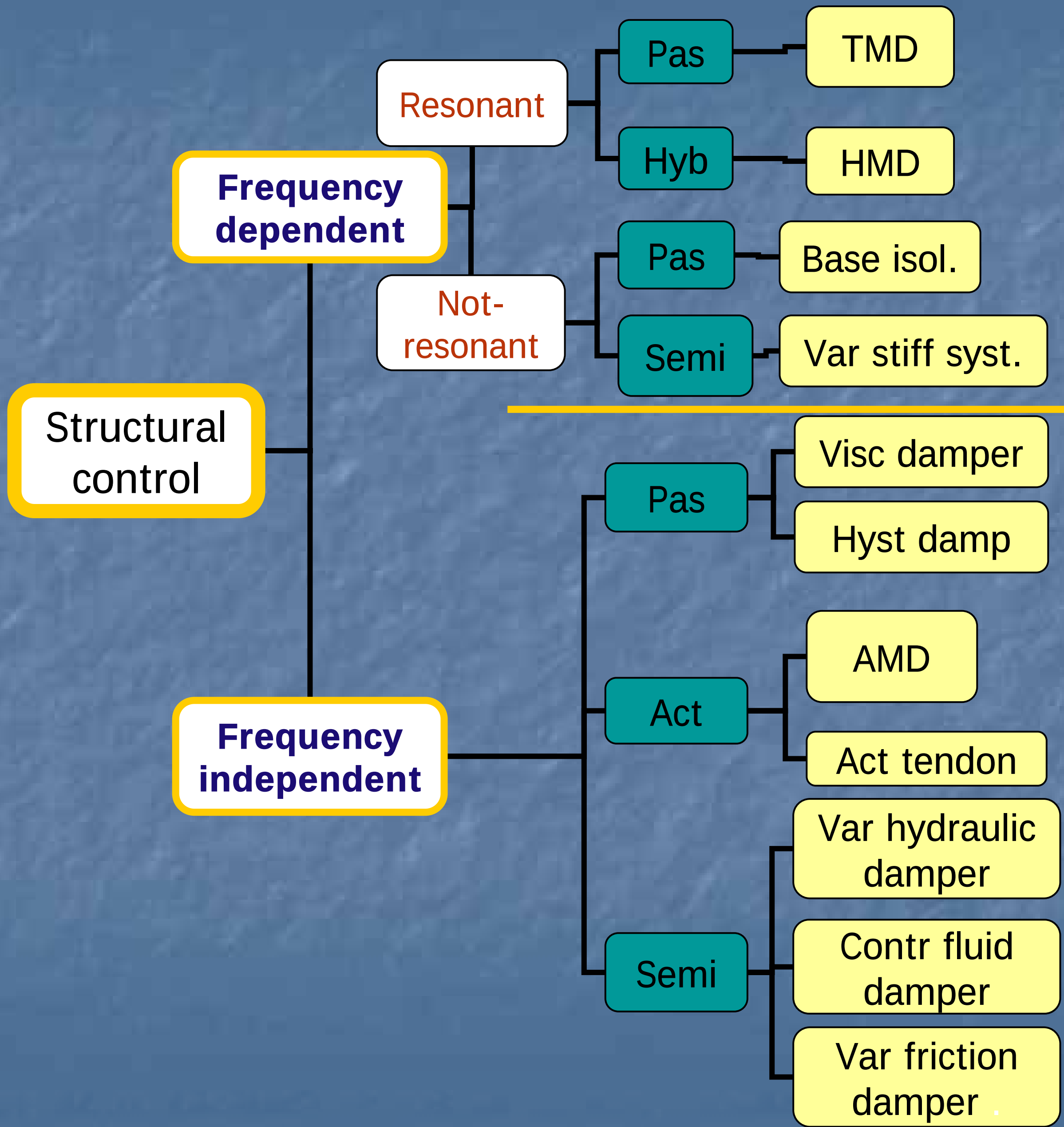
Active Control Strategies

ACTIVE DEVICES
Controllable
Significant power required

Semi-Active Control Strategies

SEMI-ACTIVE DEVICES
Controllable
Little power required

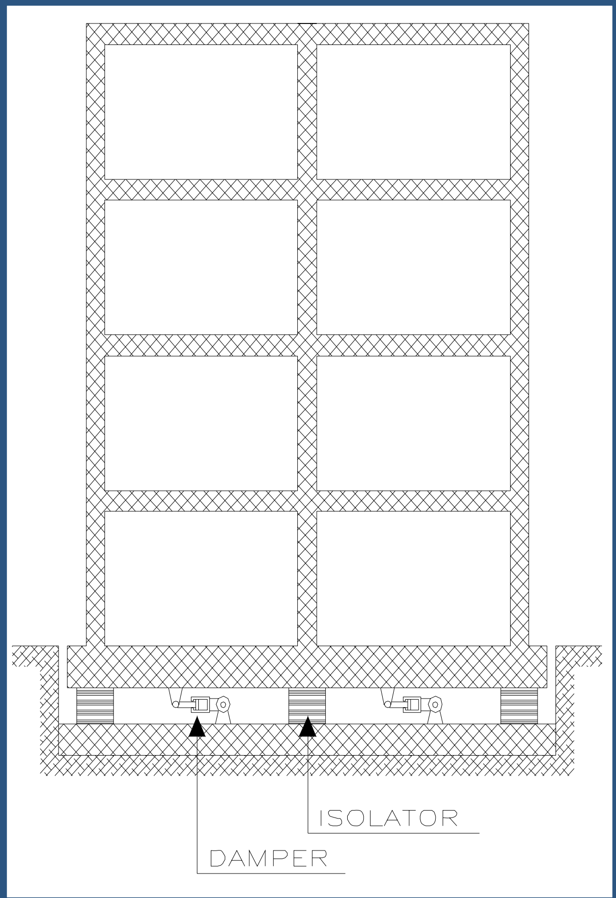
STRUCTURAL CONTROL – General considerations

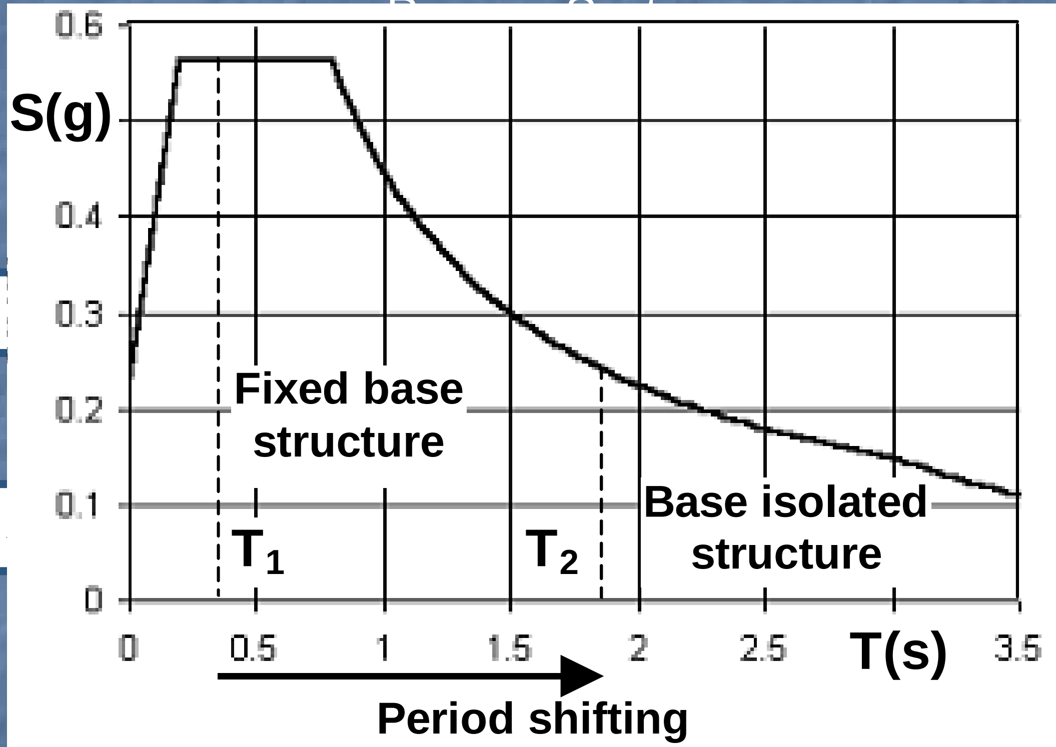


Based on systems that modify the structure natural frequencies

Based on systems that increase the structure damping capacity

CONTROL BASED ON ENERGY INPUT REDUCTION

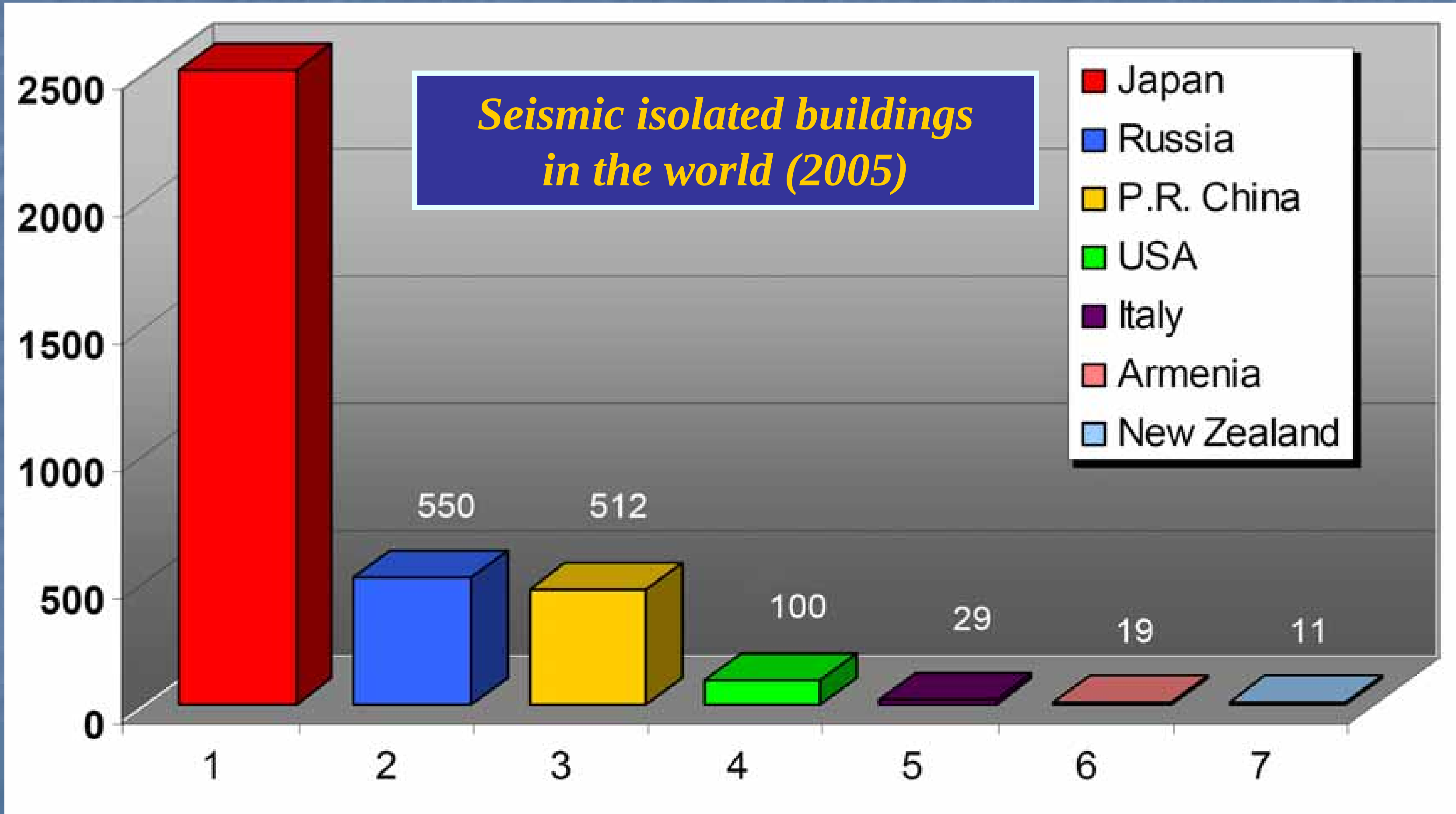




$$M\ddot{y}(t) = -M(\ddot{x}_g(t) + \ddot{x}_b(t)) - c_b\dot{x}_b(t) - k_b x_b(t)$$

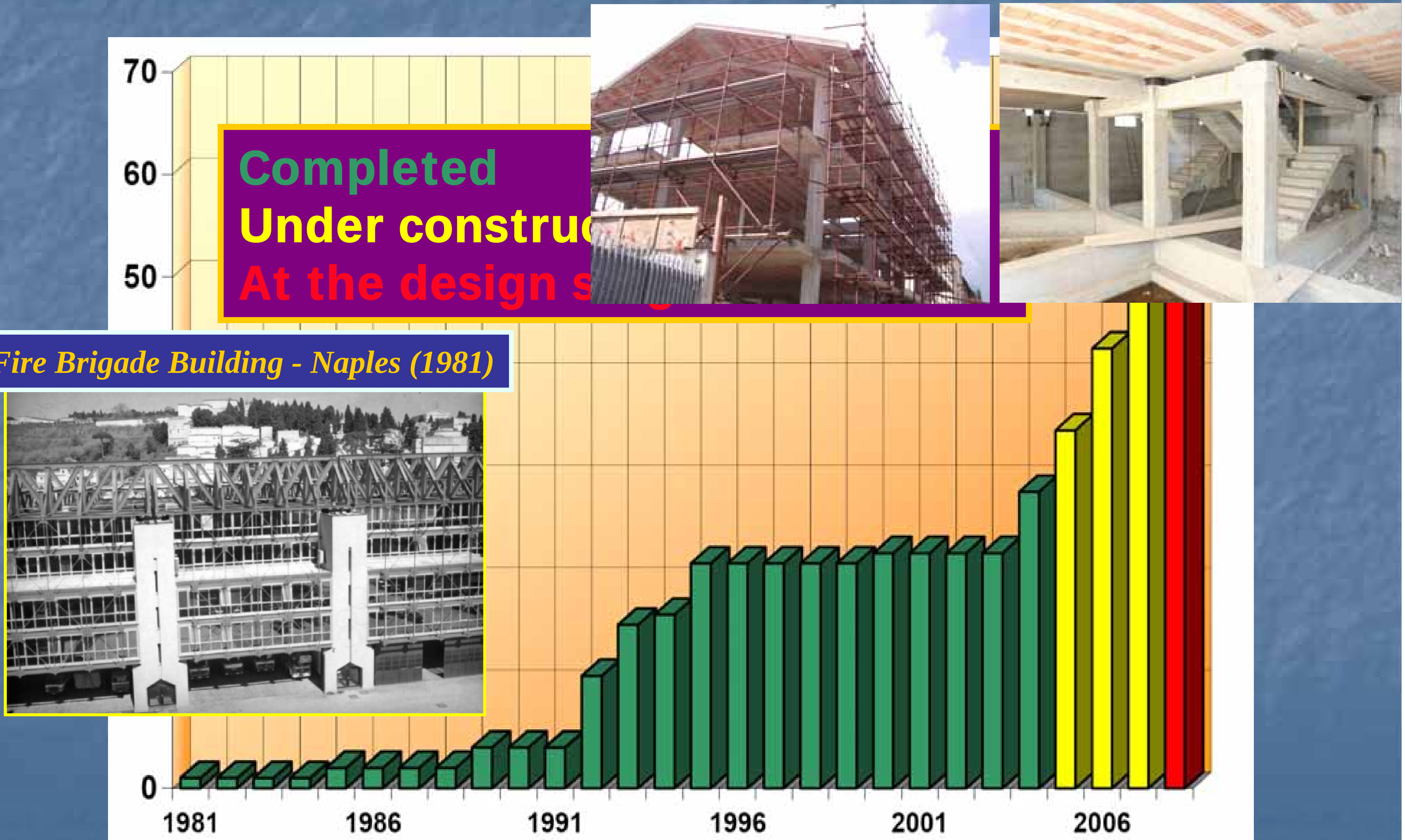
For $m_b = 0$

SEISMIC ISOLATED BUILDINGS IN THE WORLD (Courtesy GLIS)



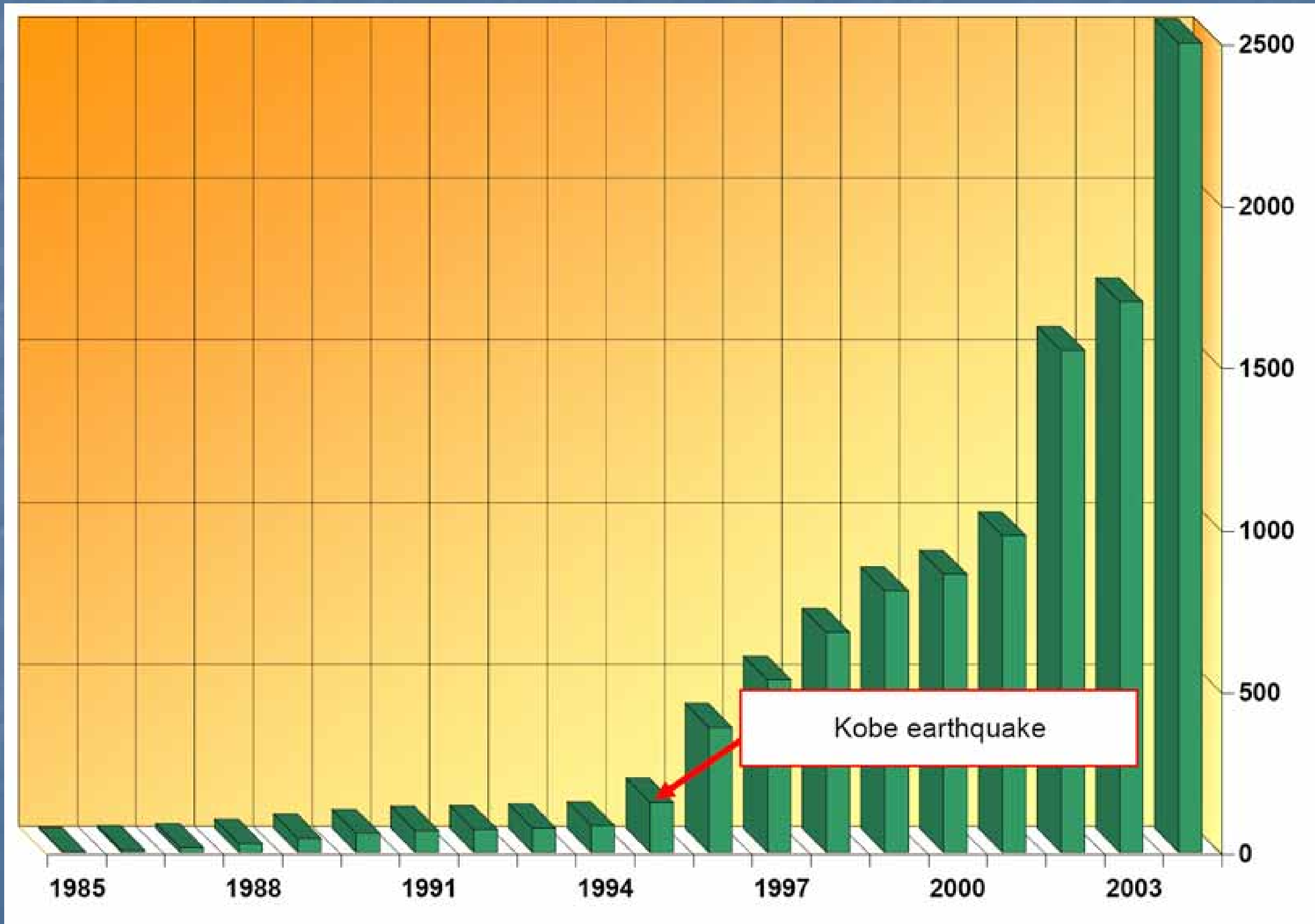
SEISMIC ISOLATED BUILDINGS IN ITALY (Courtesy GLIS)

Family house - Gricignano (2006)

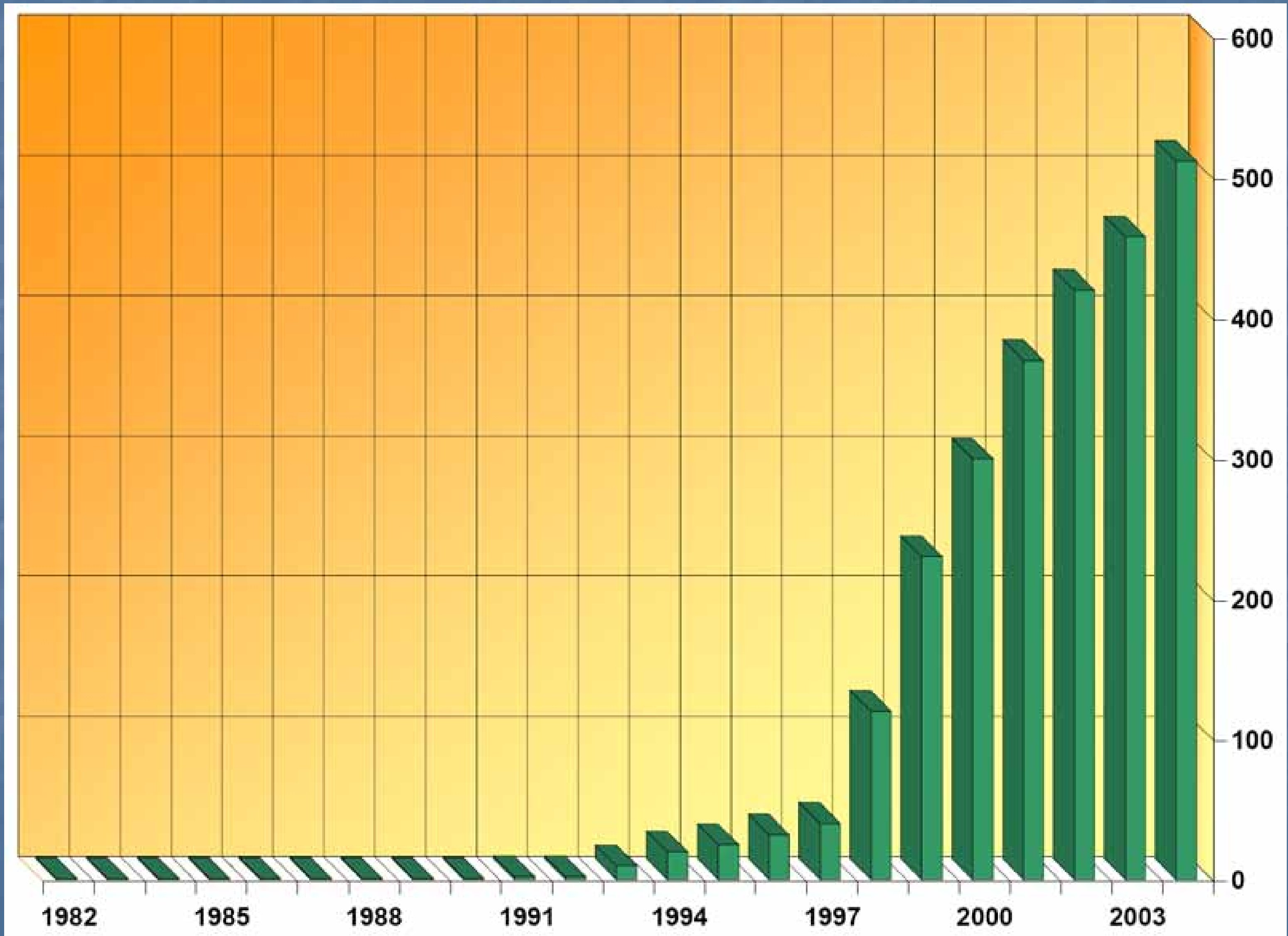


Fire Brigade Building - Naples (1981)

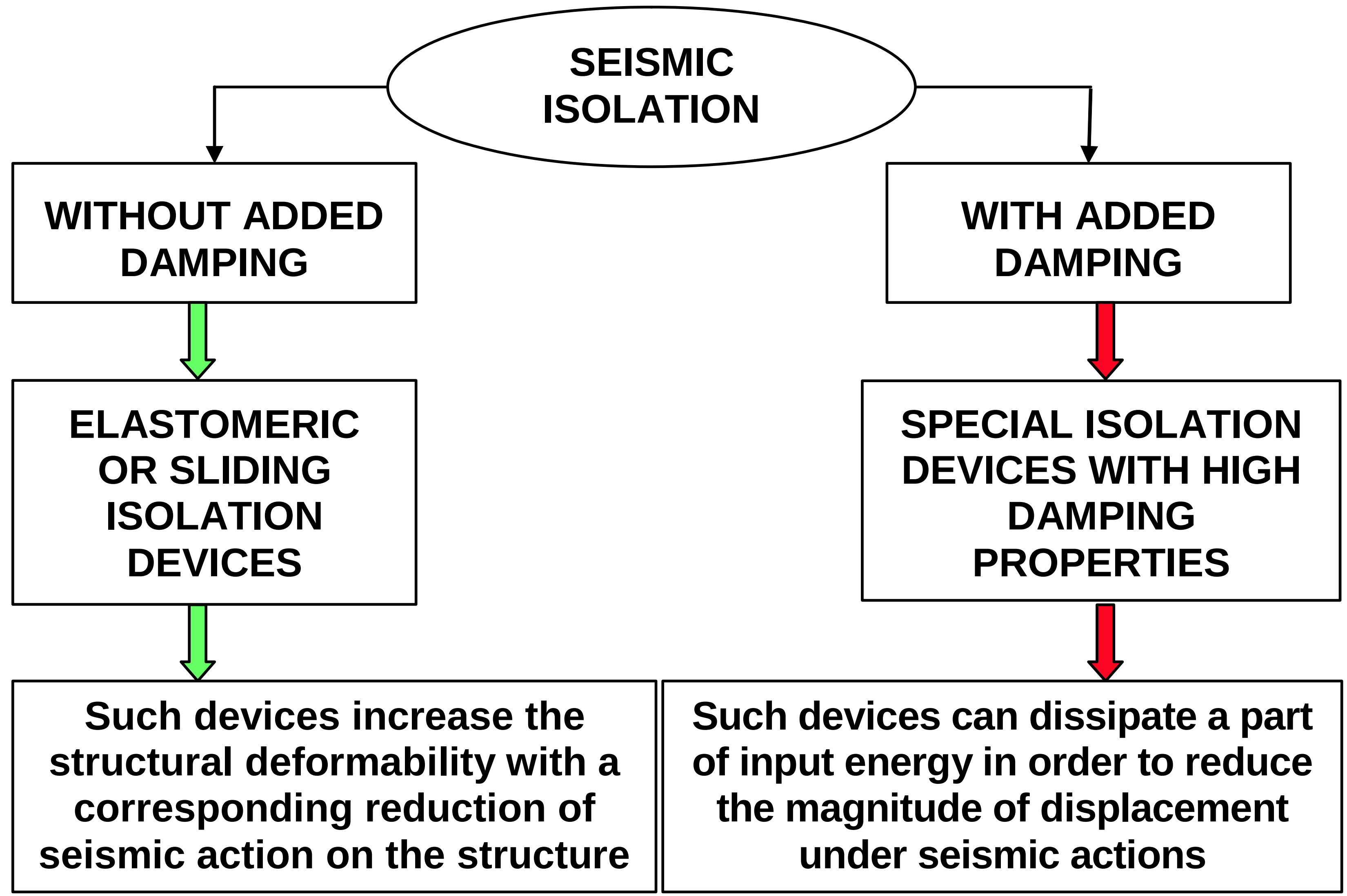
SEISMIC ISOLATED BUILDINGS IN JAPAN (Courtesy GLIS)



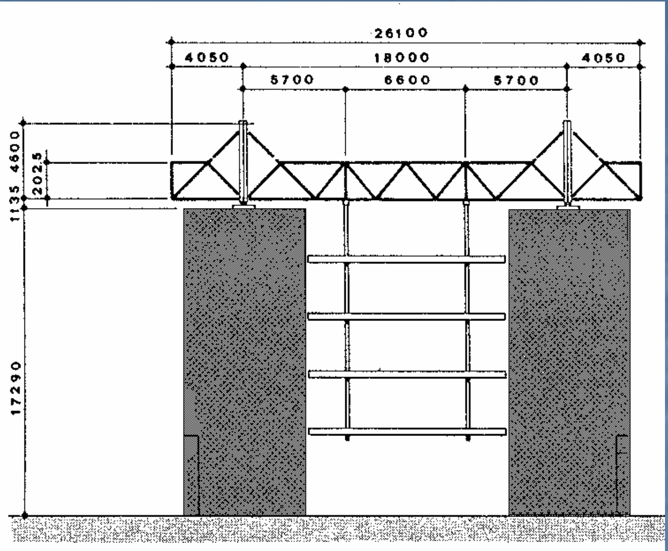
SEISMIC ISOLATED BUILDINGS IN CHINA (Courtesy GLIS)



SEISMIC ISOLATION – BASIC OPTIONS

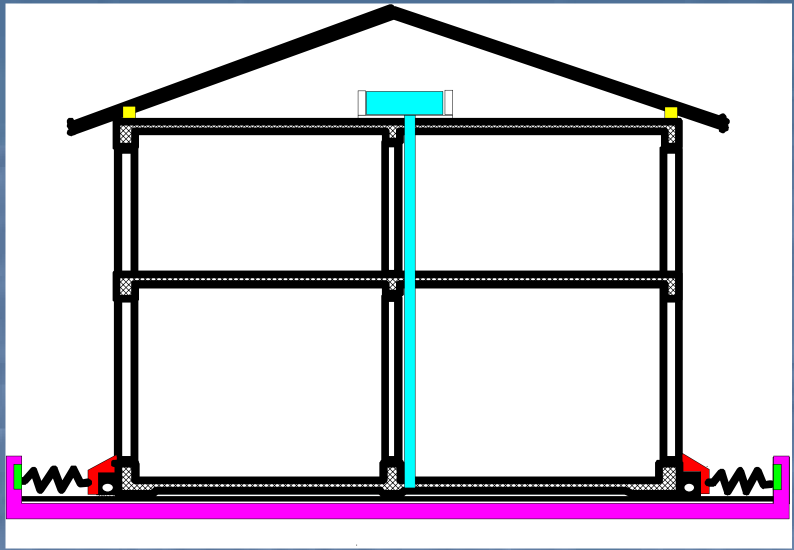


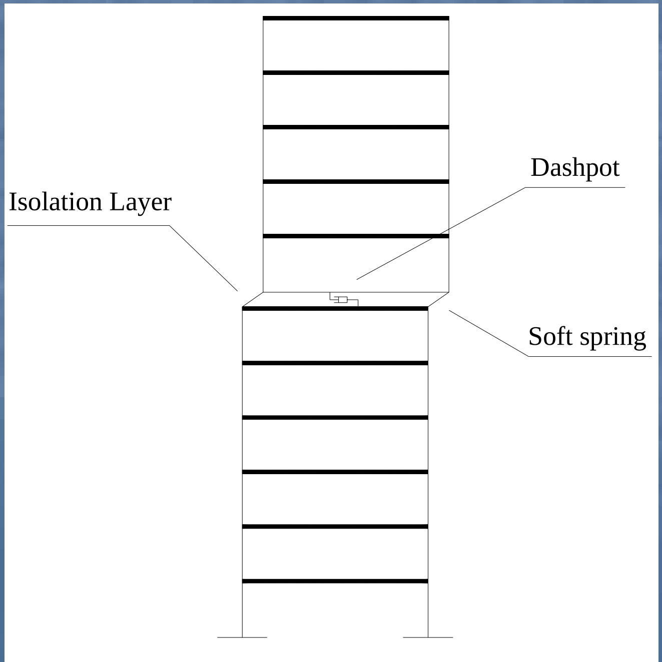
ISOLATION SYSTEMS



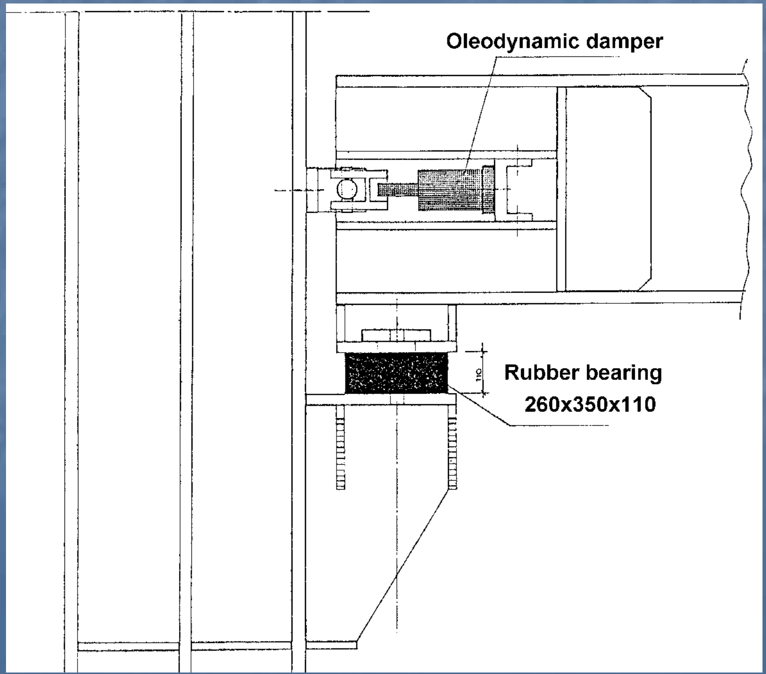
Top isolation

ALSC





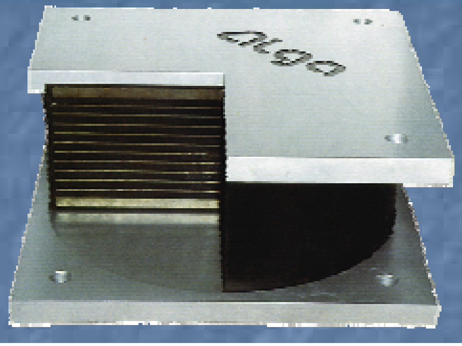
Partial isolation

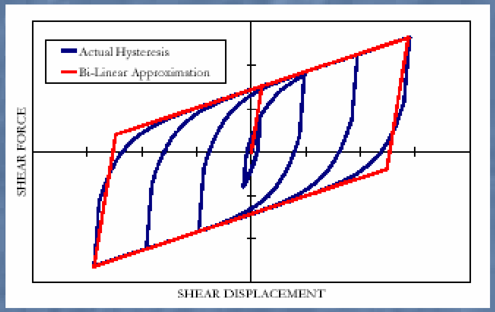


Floor isolation

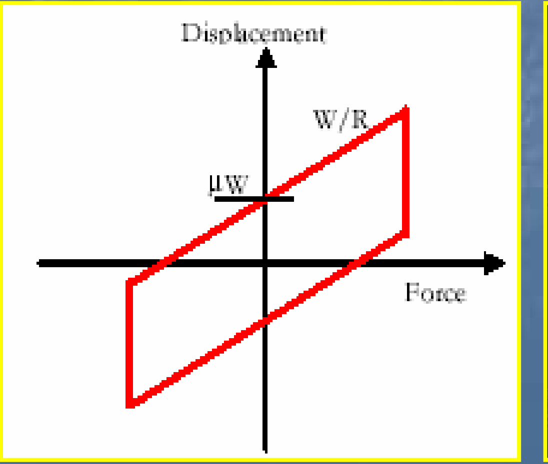
ISOLATION DEVICES

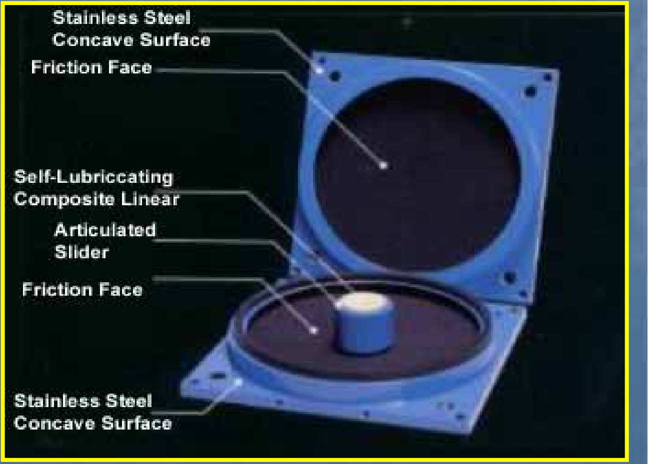
RUBBER BEARINGS



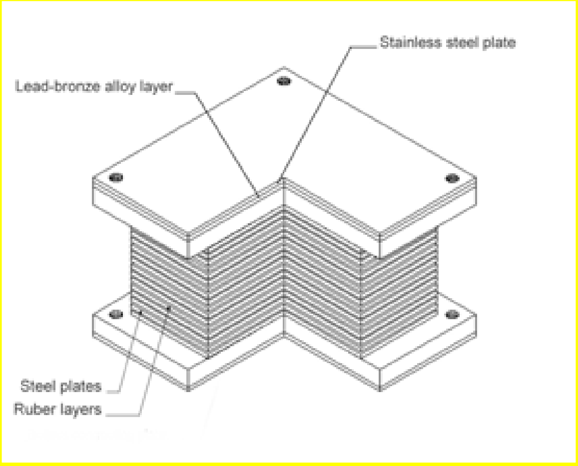


SLIDING BEARINGS

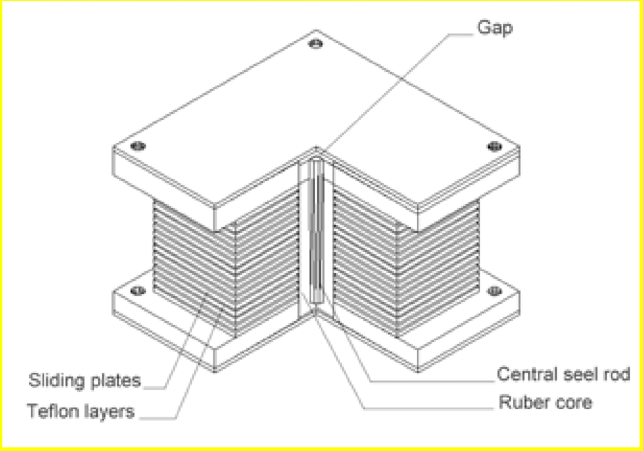




SPECIAL ISOLATION DEVICES

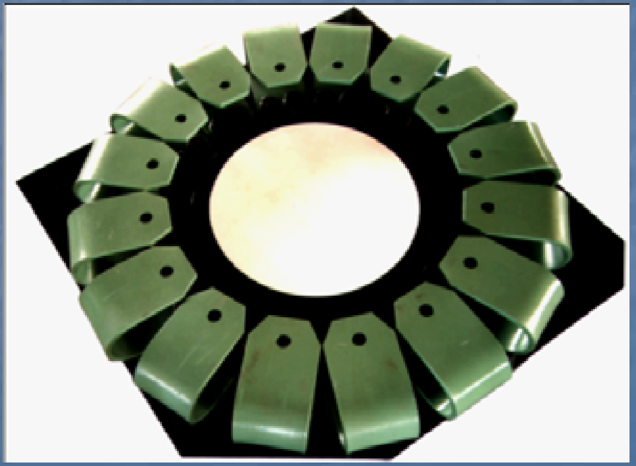


Resilient-Friction Base Isolators

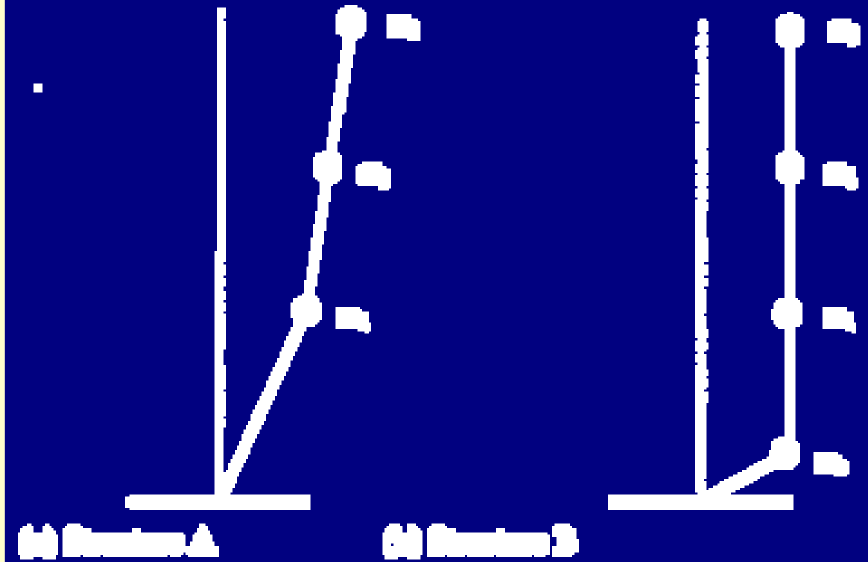


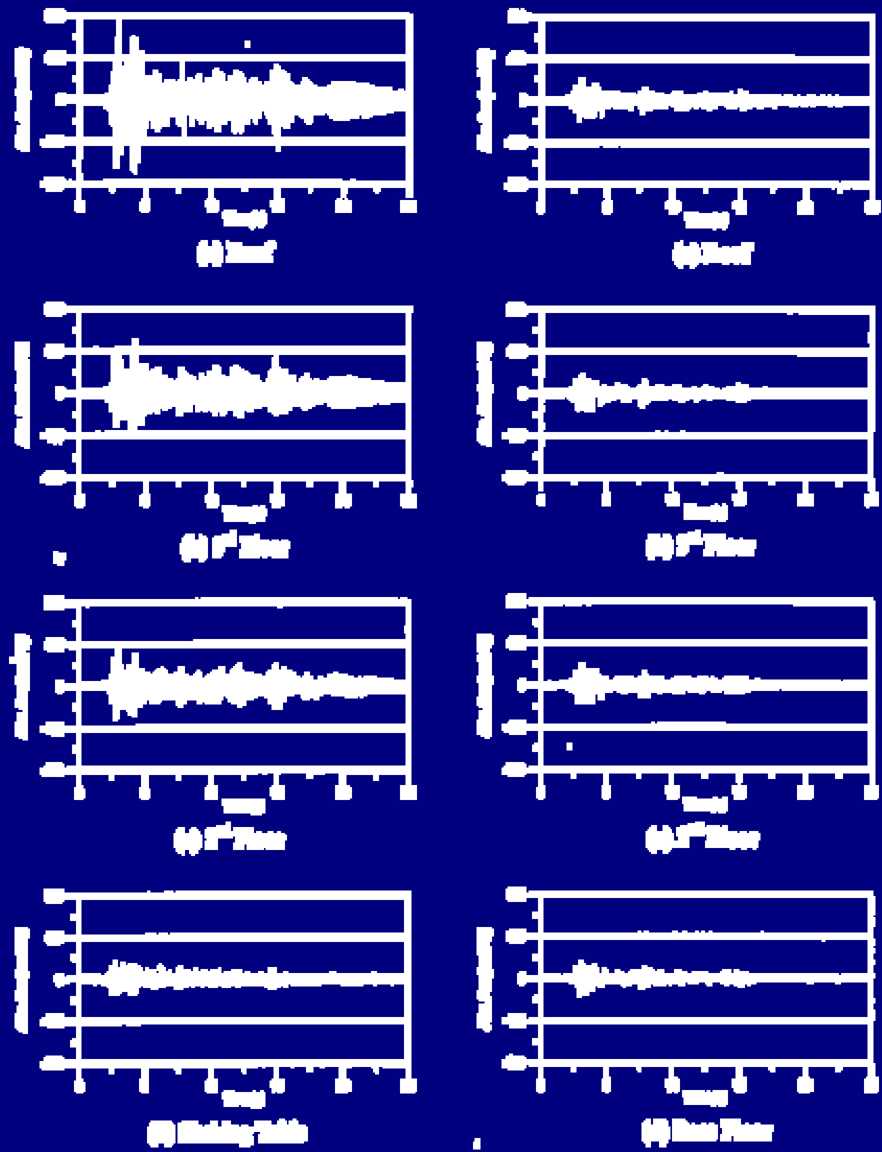
Wire-rope bearings

Elasto-plastic bearings



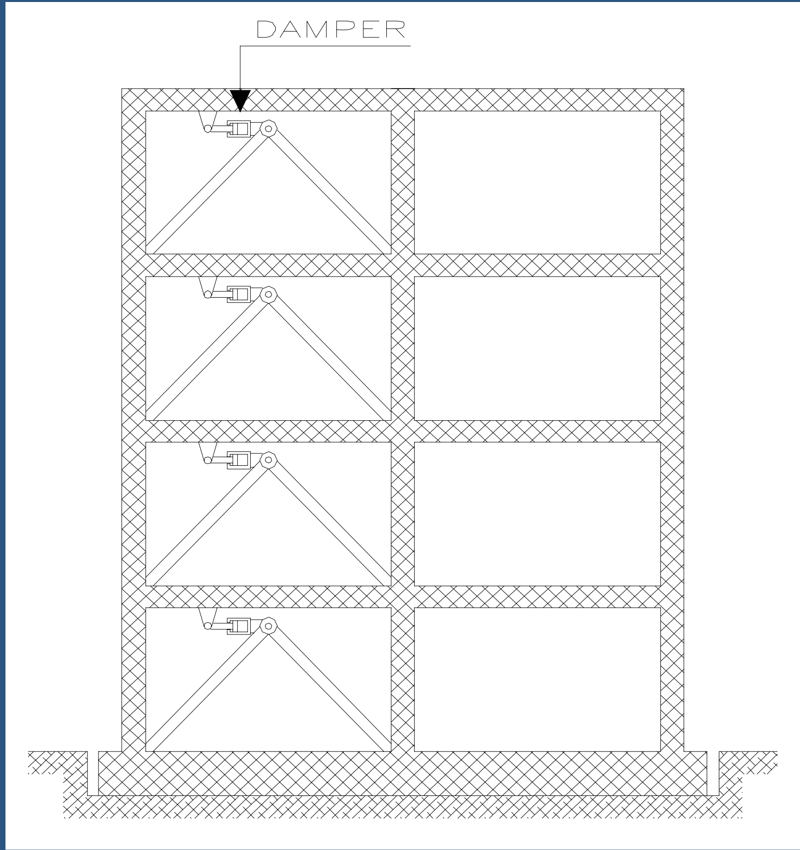
STRUCTURAL RESPONSE OF ISOLATED STRUCTURES



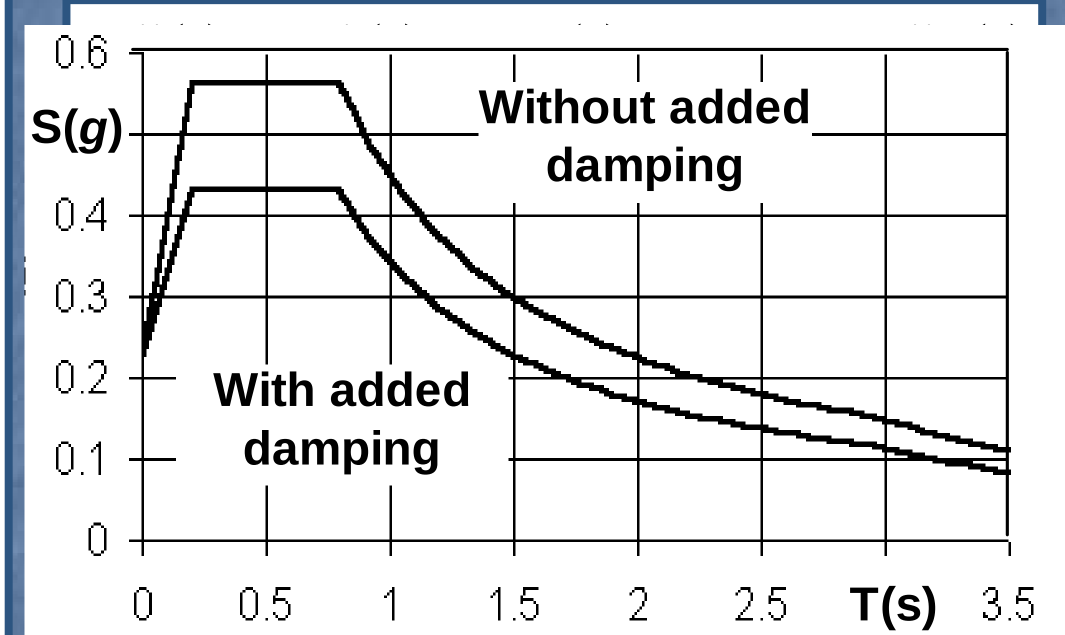


ADDITIONAL ENERGY DISSIPATION

CONTROL BASED ON ADDED DAMPING

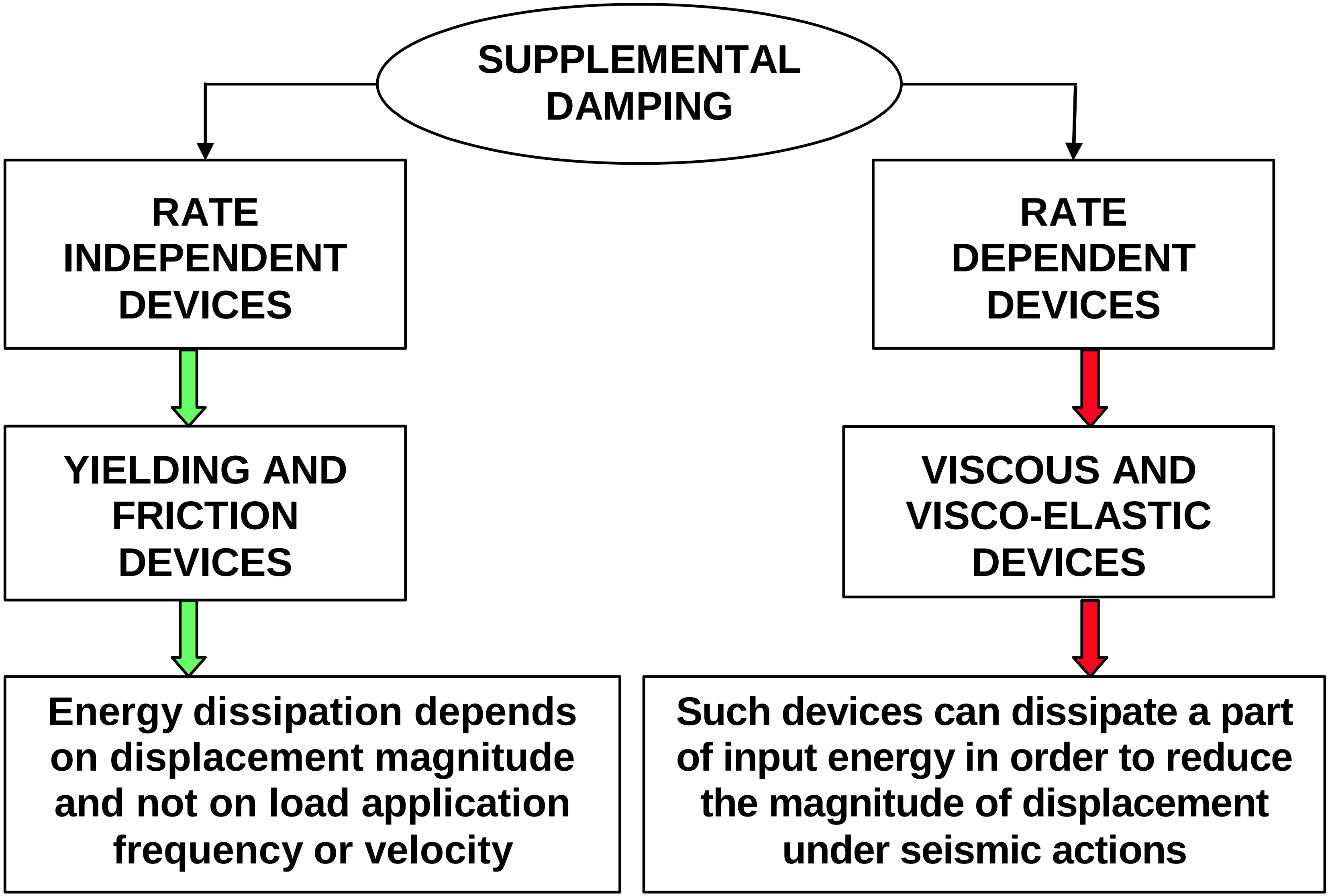


Primary System

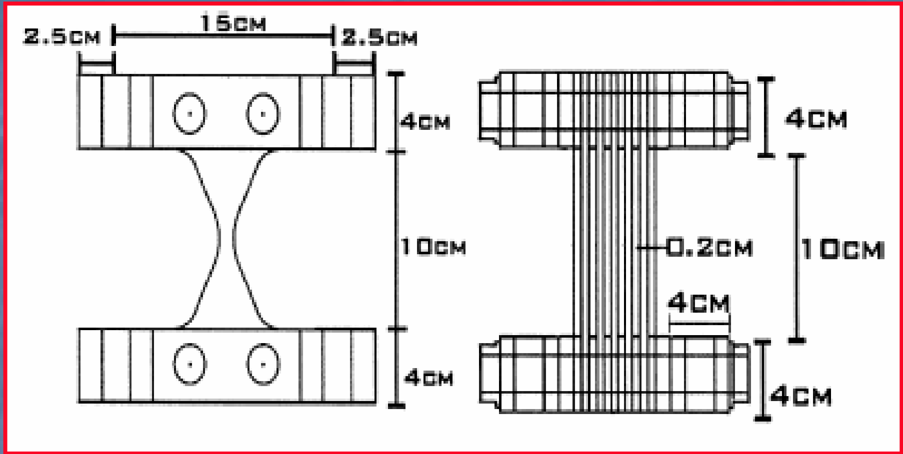


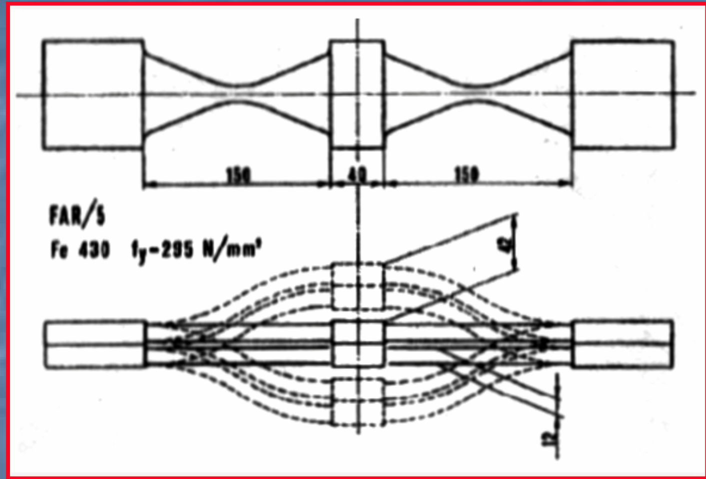
$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = -m\ddot{x}_g(t) - \underline{c}\dot{x}(t)$$

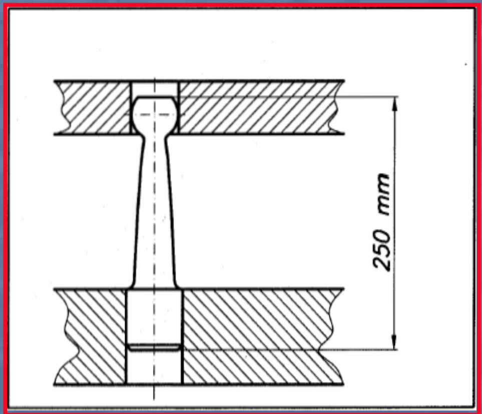
SUPPLEMENTAL DAMPING – BASIC OPTIONS

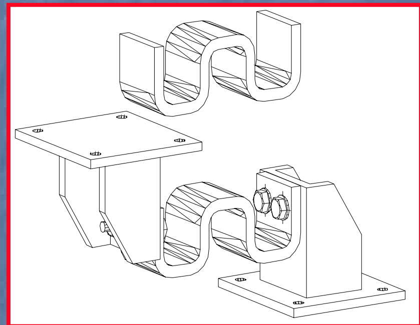


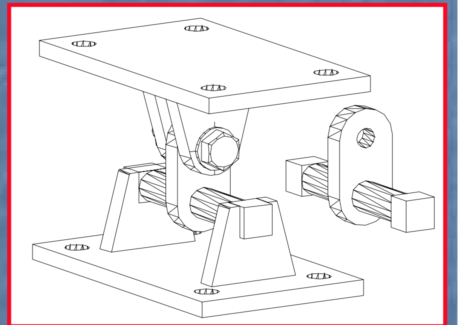
HYSTERETIC YIELDING METAL DEVICES

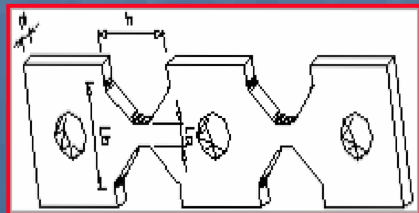




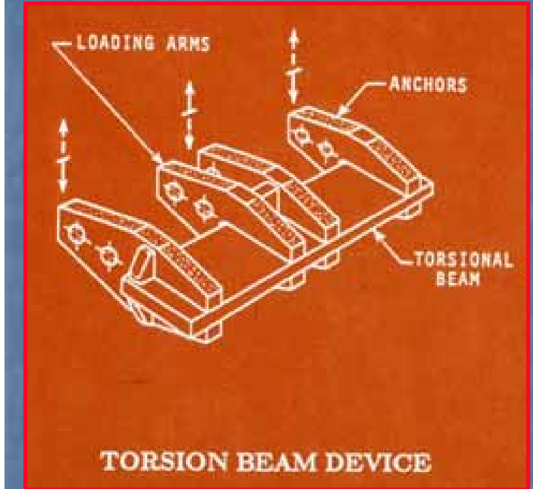


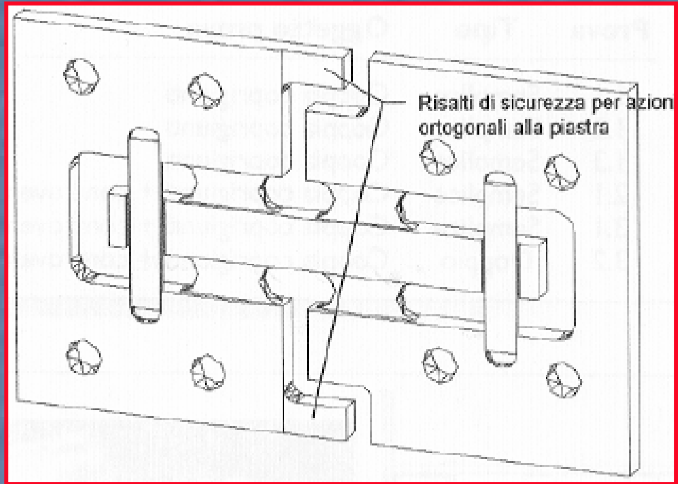


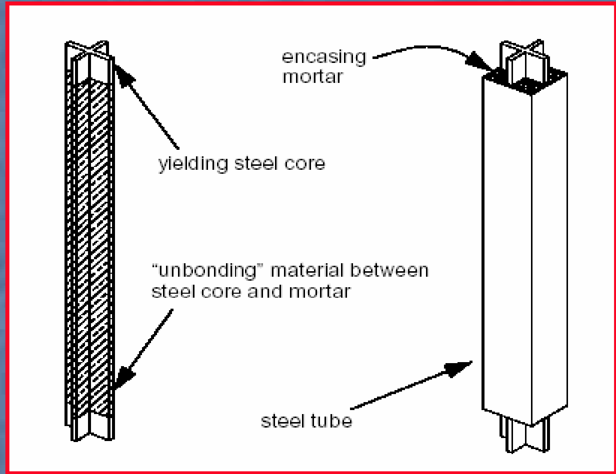


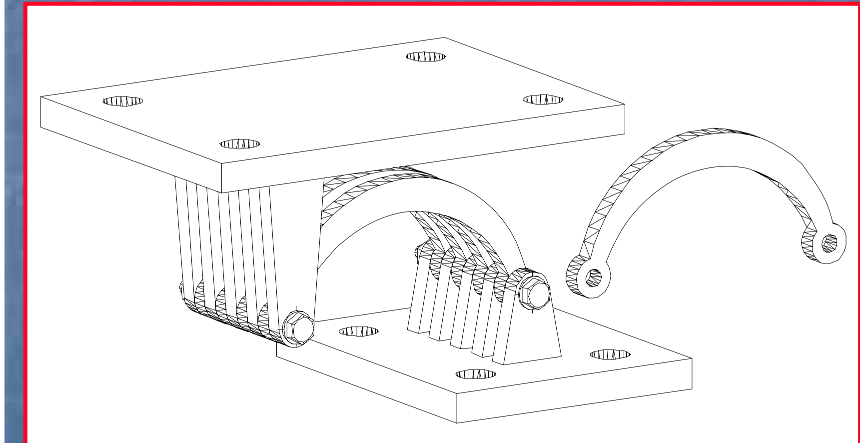


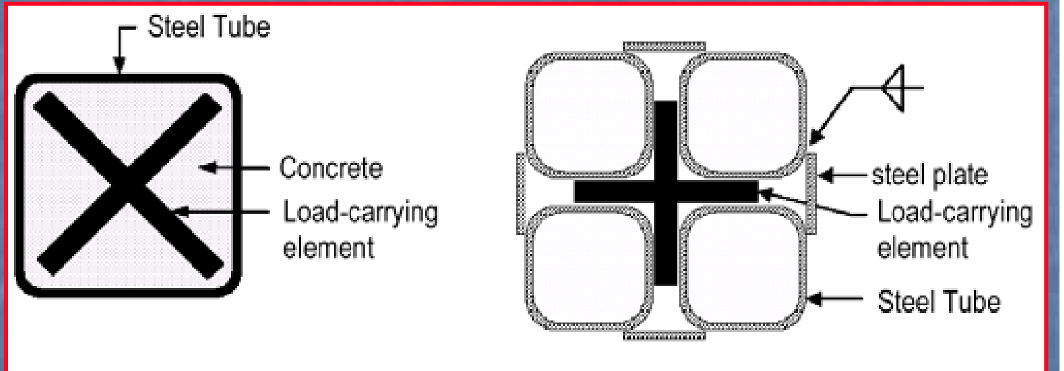
HYSTERETIC YIELDING METAL DEVICES







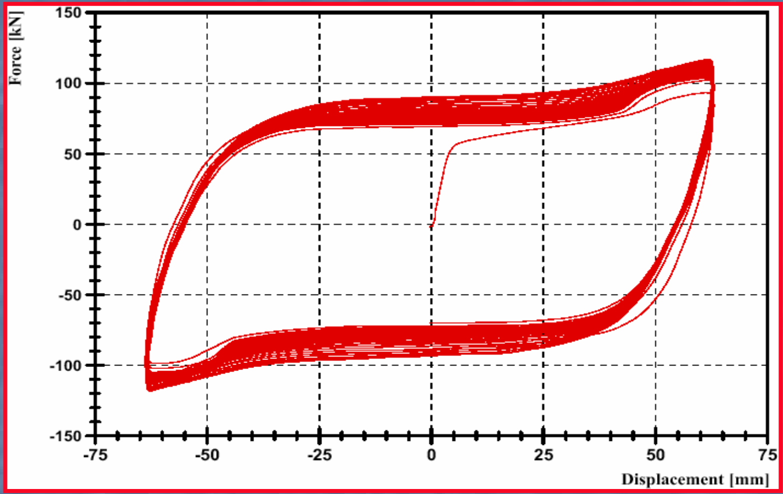


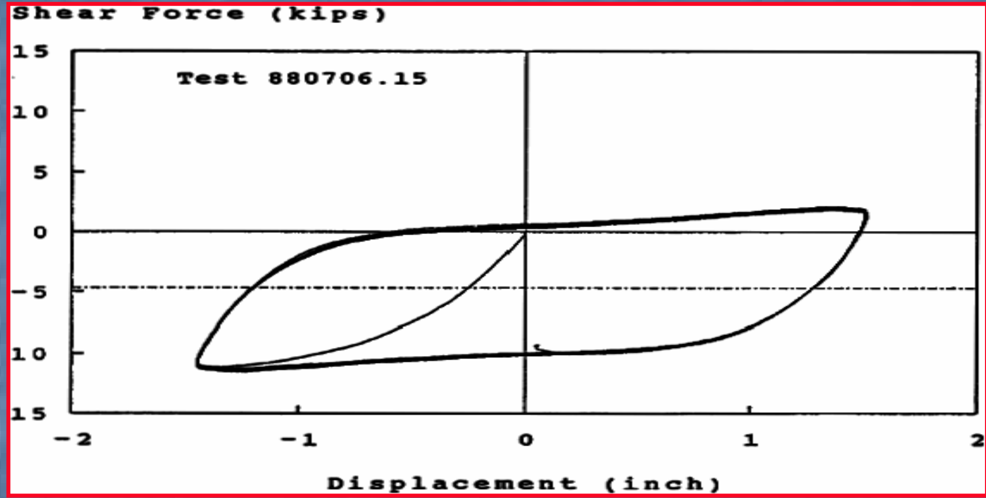


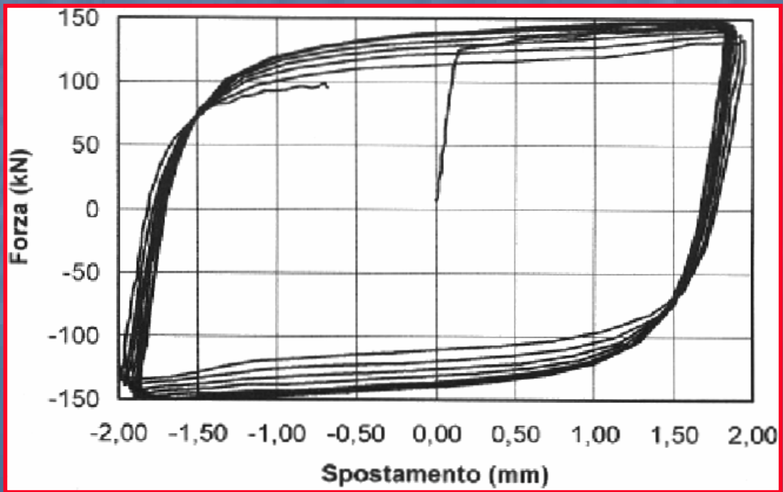
(a) Concrete-filled tube

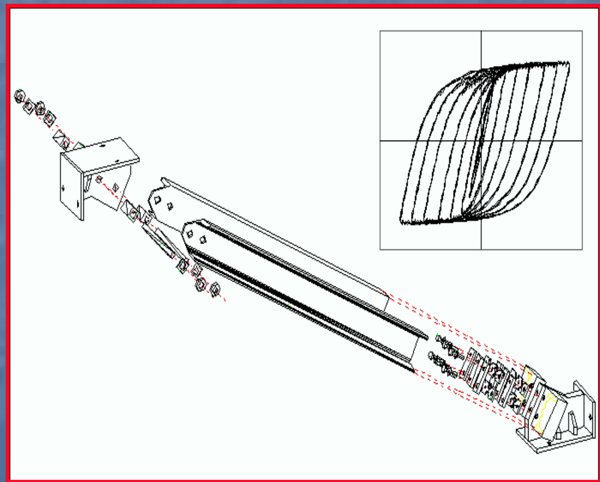
(b) Build-up steel section

HYSTERETIC YIELDING METAL DEVICES

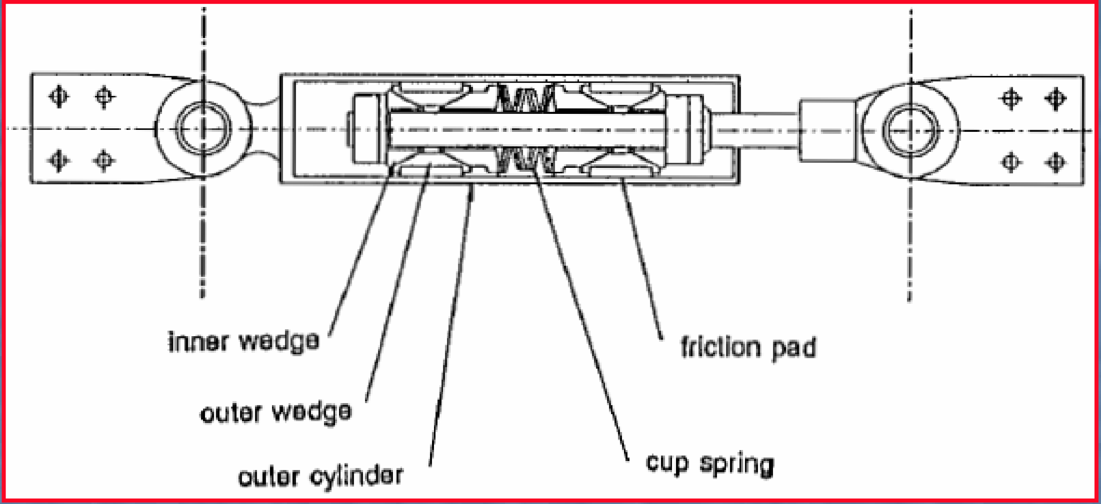


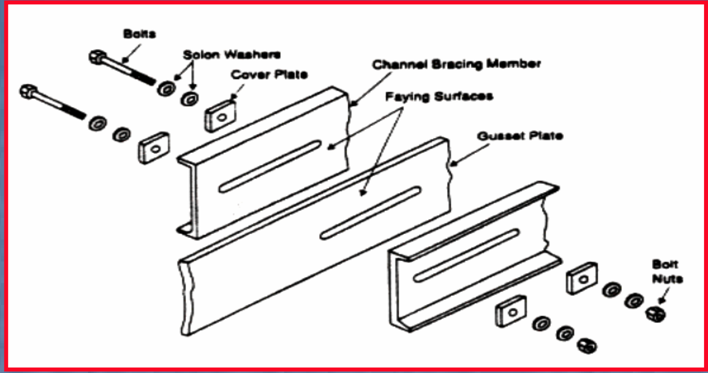


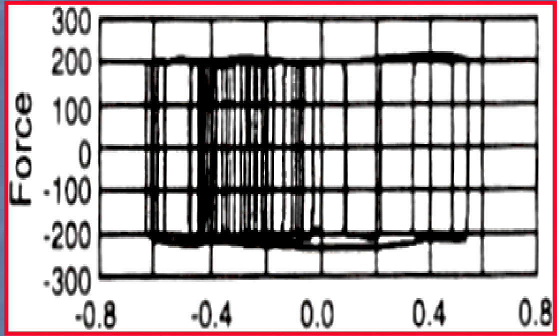


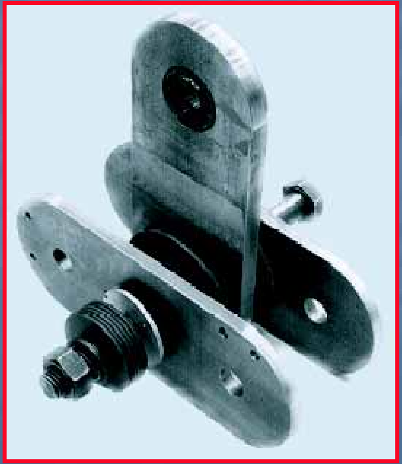


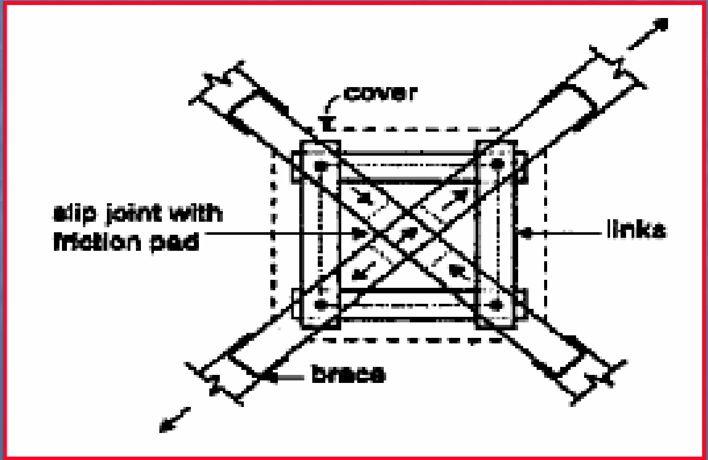
HYSTERETIC FRICTION DEVICES

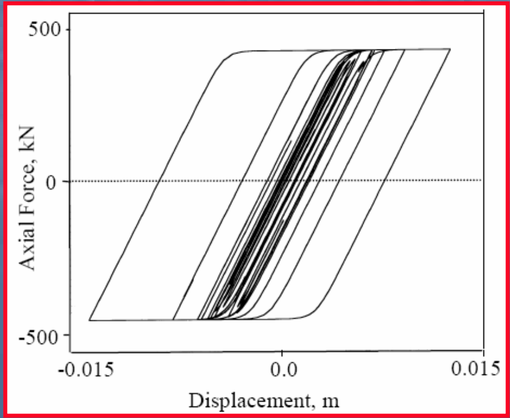




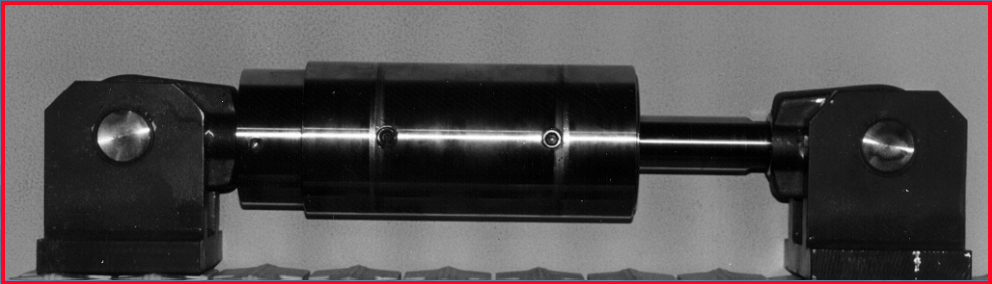


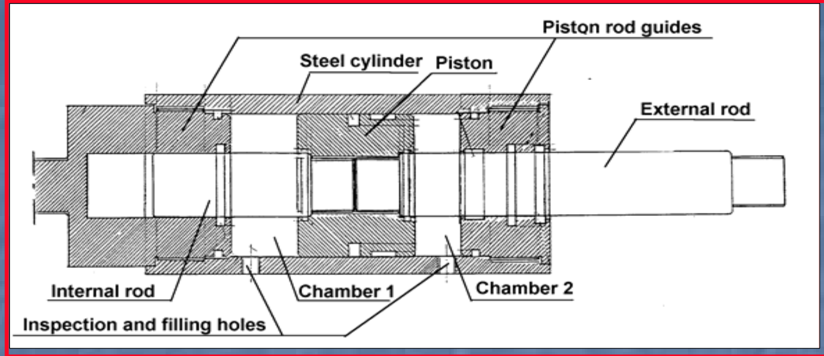


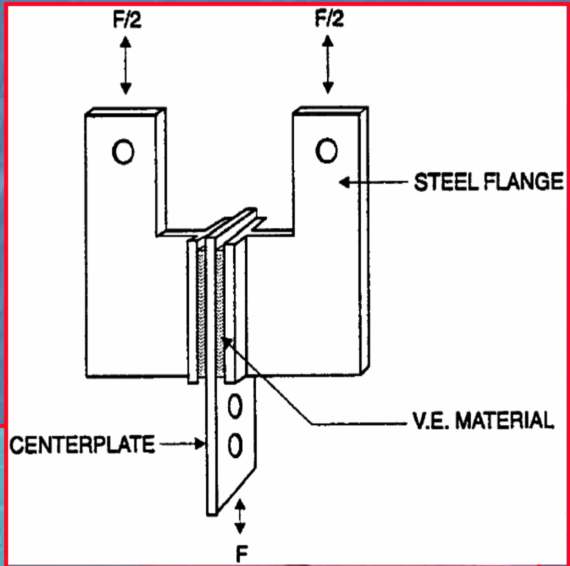


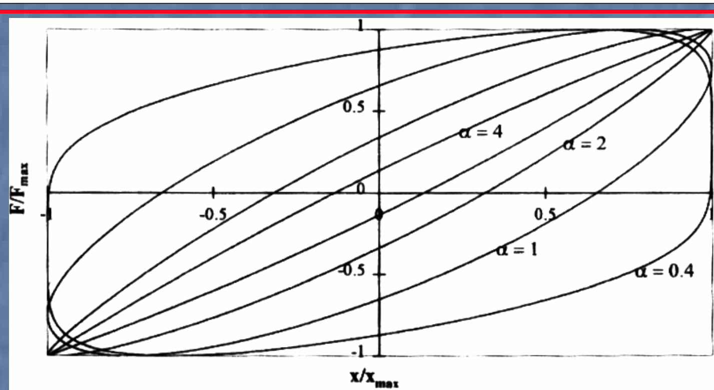


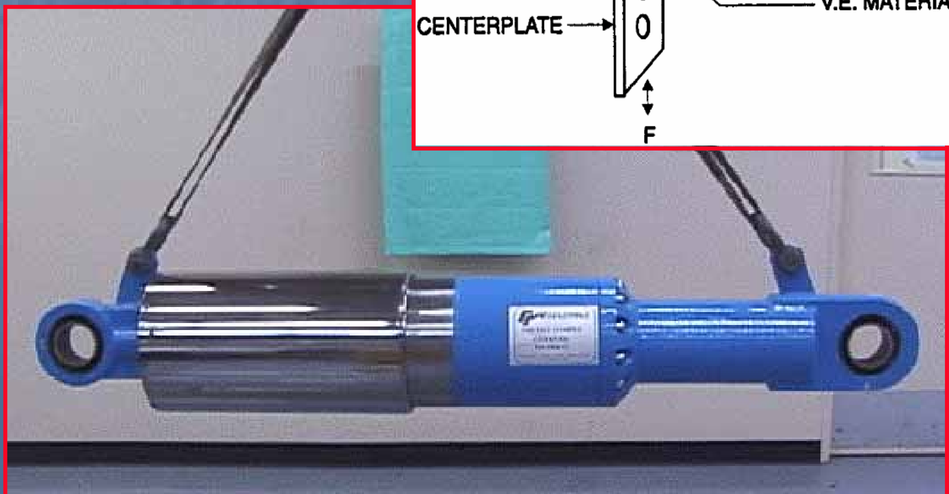
VISCOUS AND VISCO-ELASTIC DAMPERS

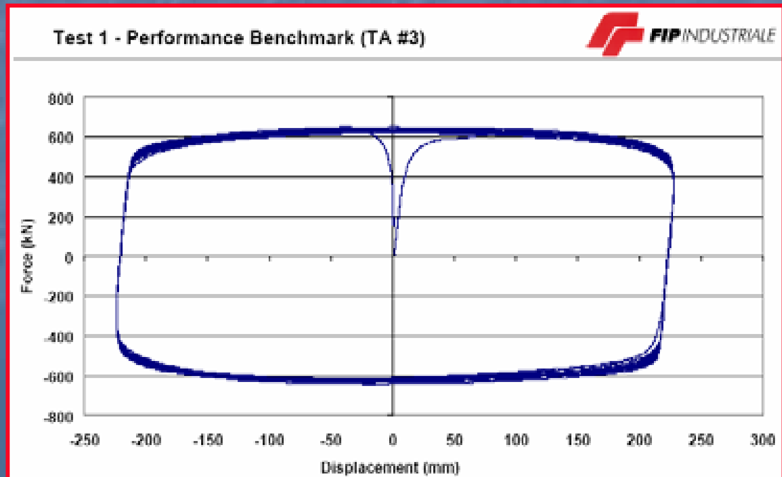






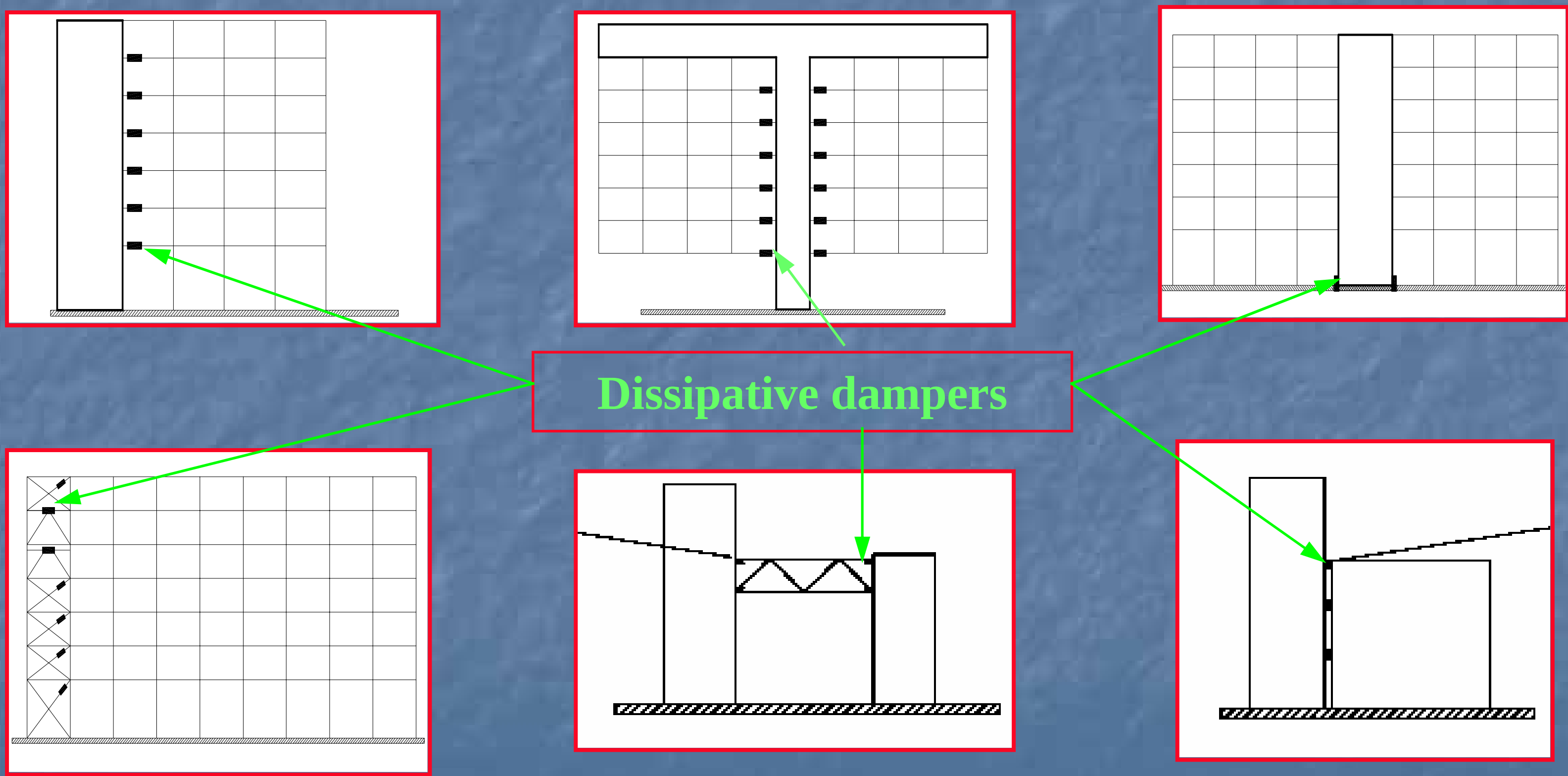






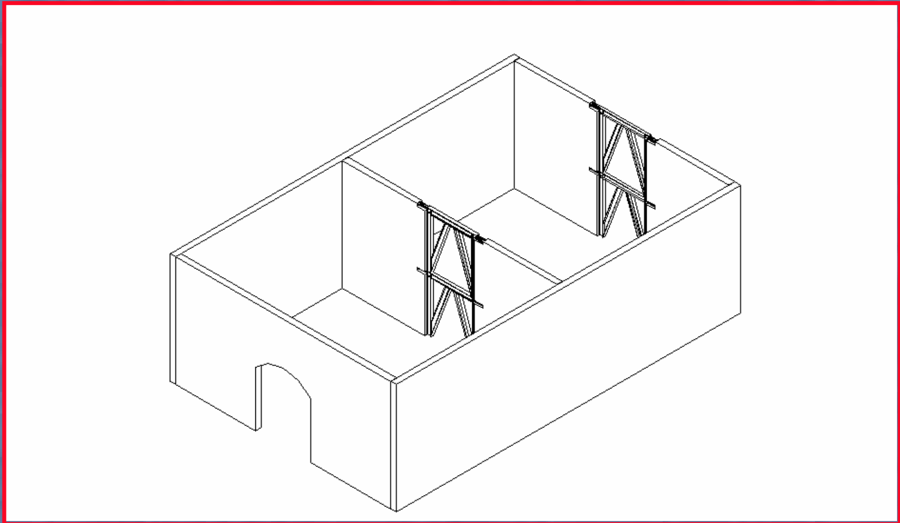
ENERGY DISSIPATION SYSTEMS

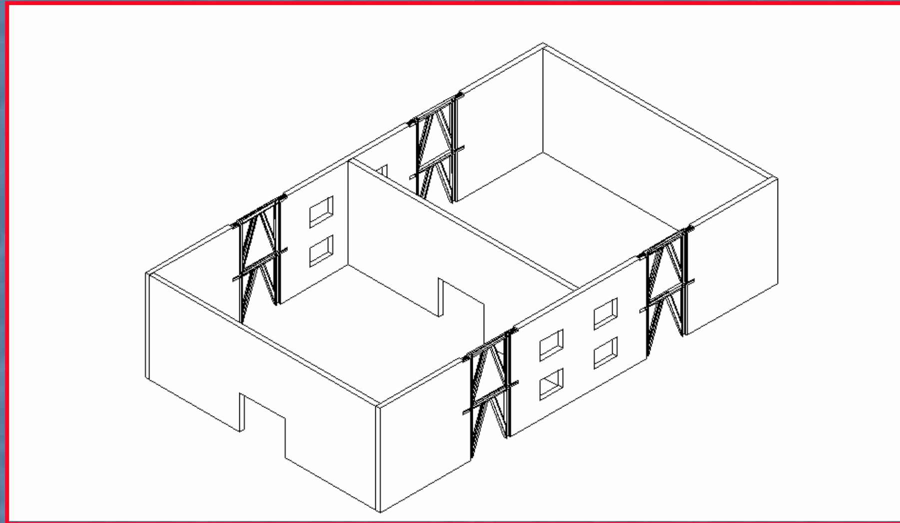
STRUCTURAL IMPLEMENTATION

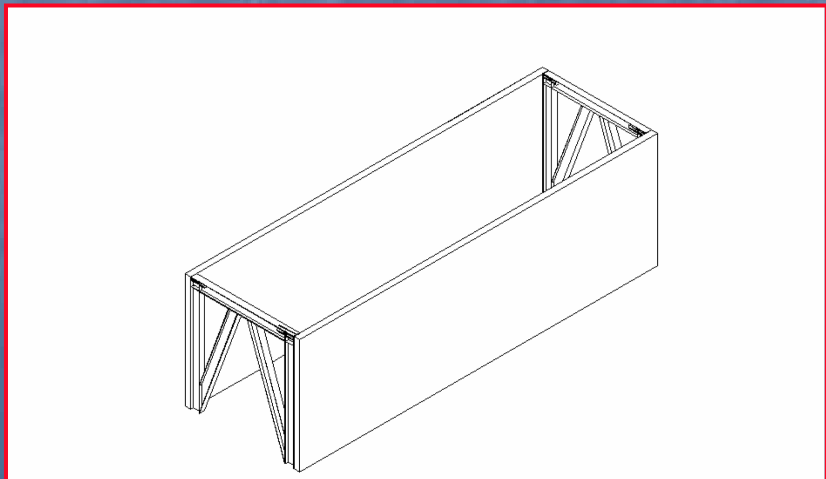


ENERGY DISSIPATION SYSTEMS

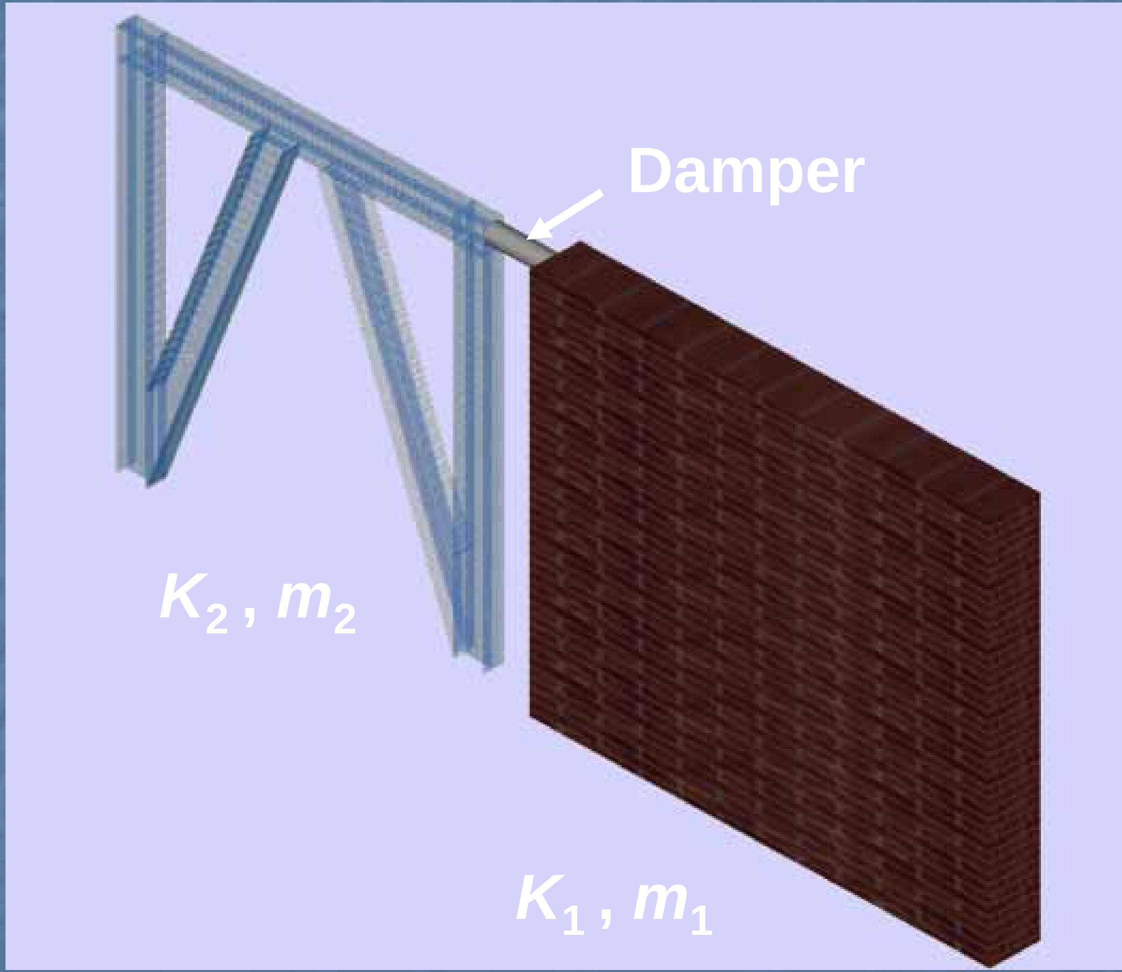
STRUCTURAL IMPLEMENTATION







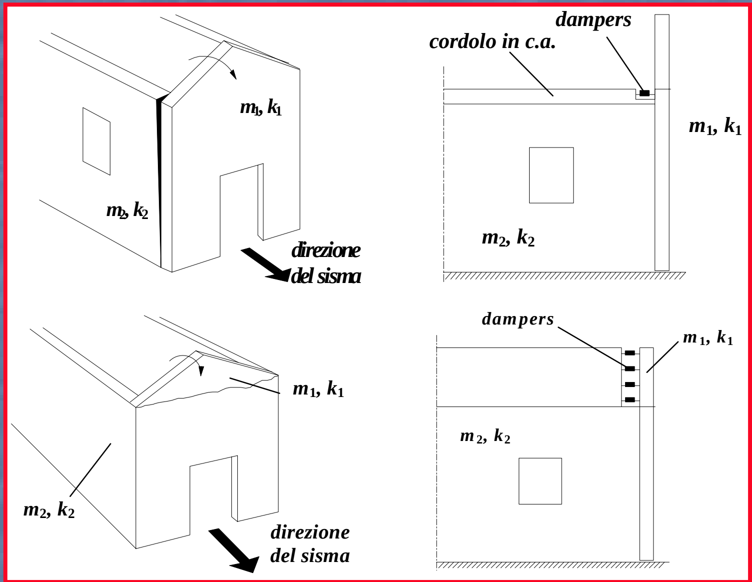
STRUCTURAL IMPLEMENTATION

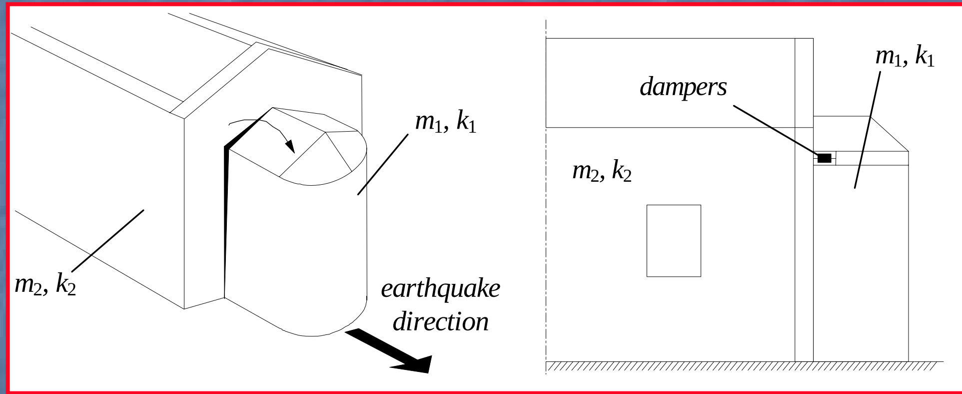


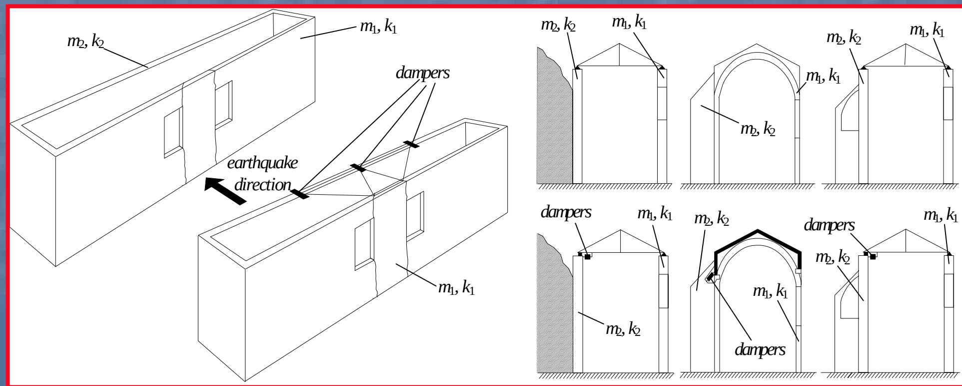
$$(K_1 / m_1) \neq (K_2 / m_2)$$

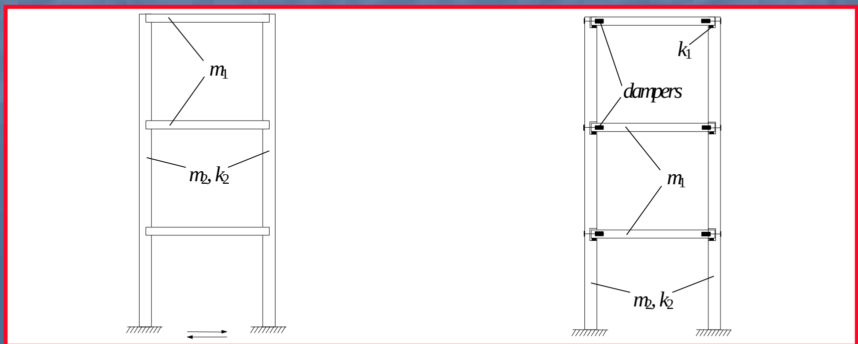
ENERGY DISSIPATION SYSTEMS

STRUCTURAL IMPLEMENTATION



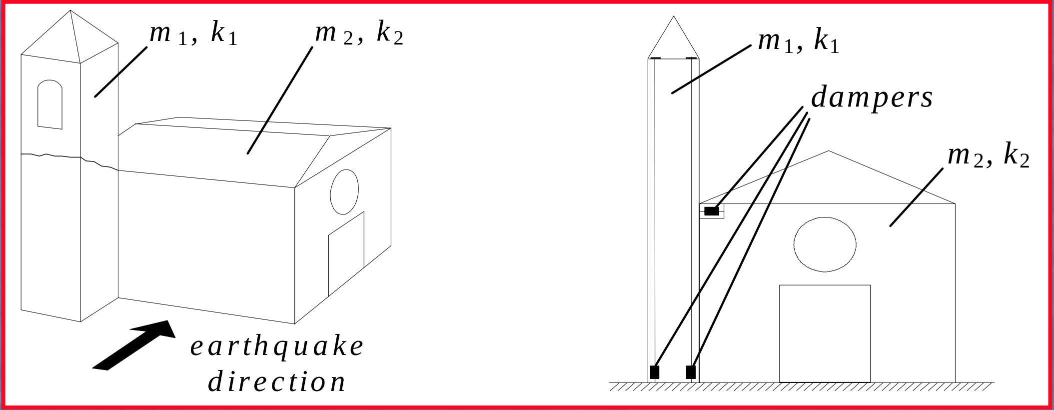


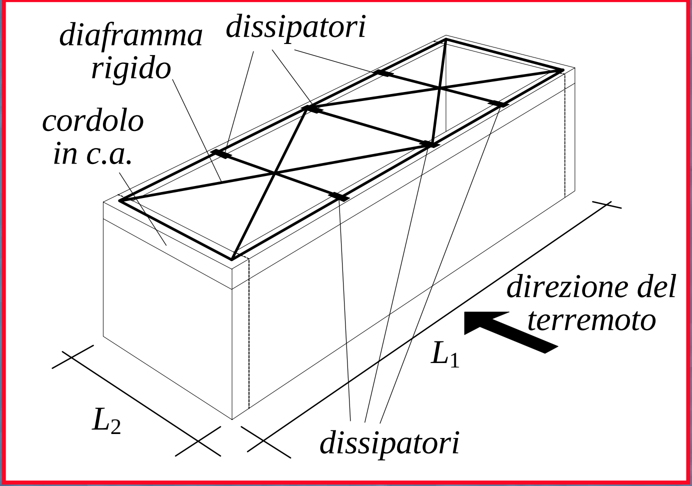


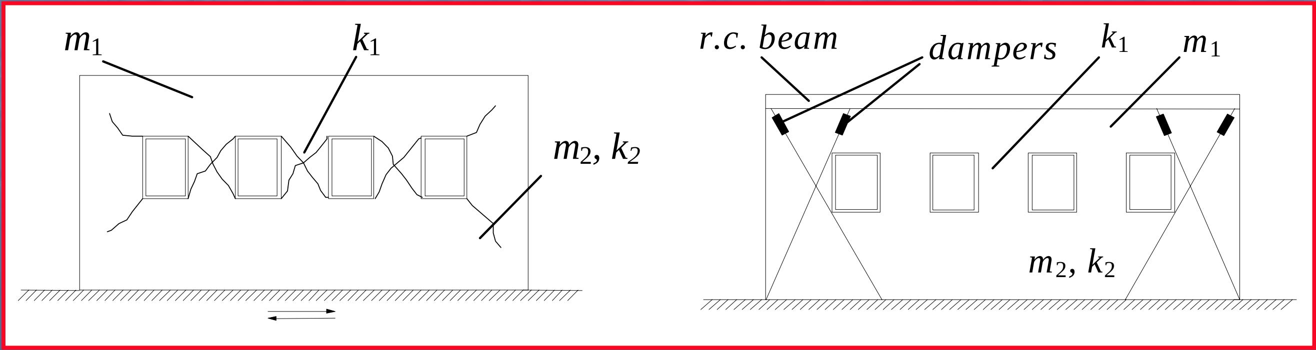


ENERGY DISSIPATION SYSTEMS

STRUCTURAL IMPLEMENTATION







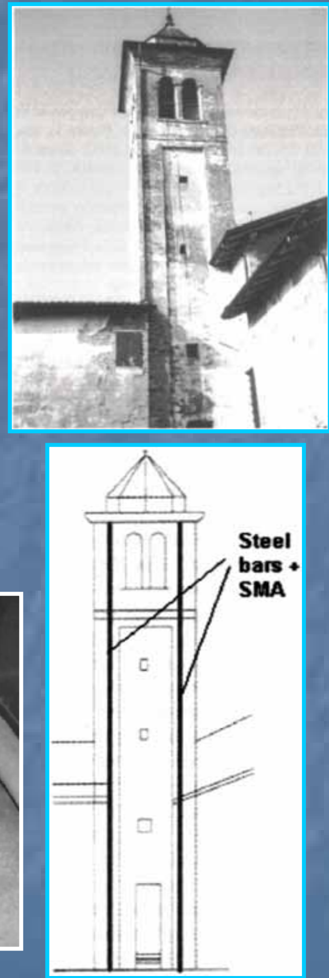
ENERGY DISSIPATION SYSTEMS

STRUCTURAL IMPLEMENTATION – EXISTING APPLICATIONS

Industrial shed Sarno

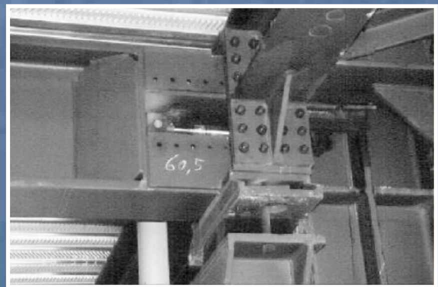
Church of San Giovanni Battista in Carife

Basilica Superiore of San Francesco in Assisi



Bell tower of San Giorgio in Trignano

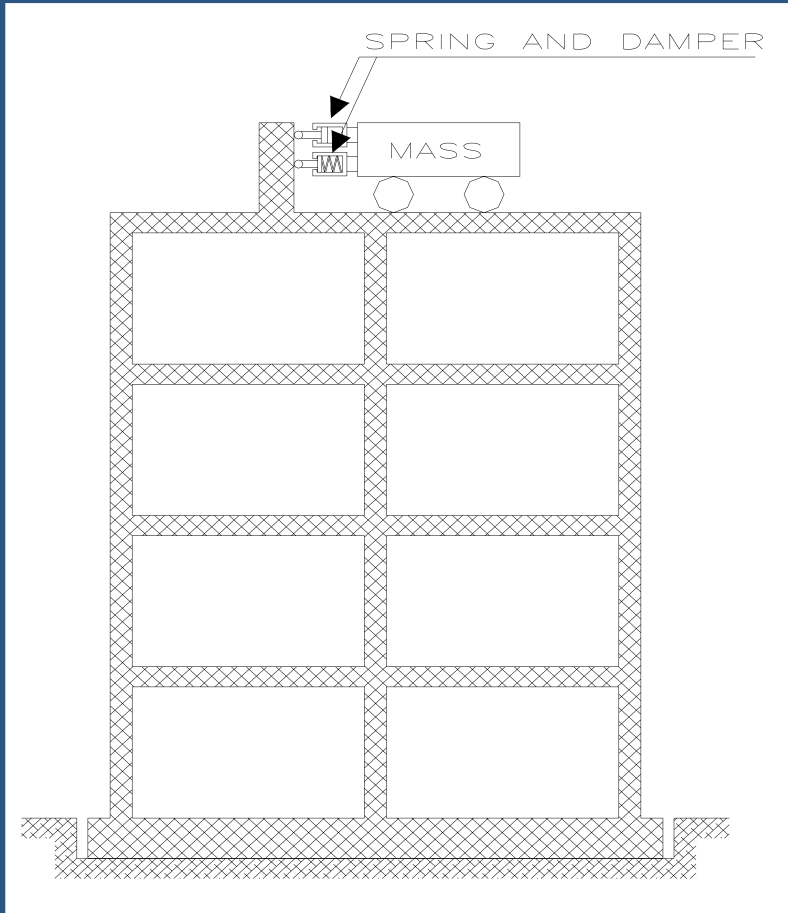
Scuola Superiore Gentile-Fermi

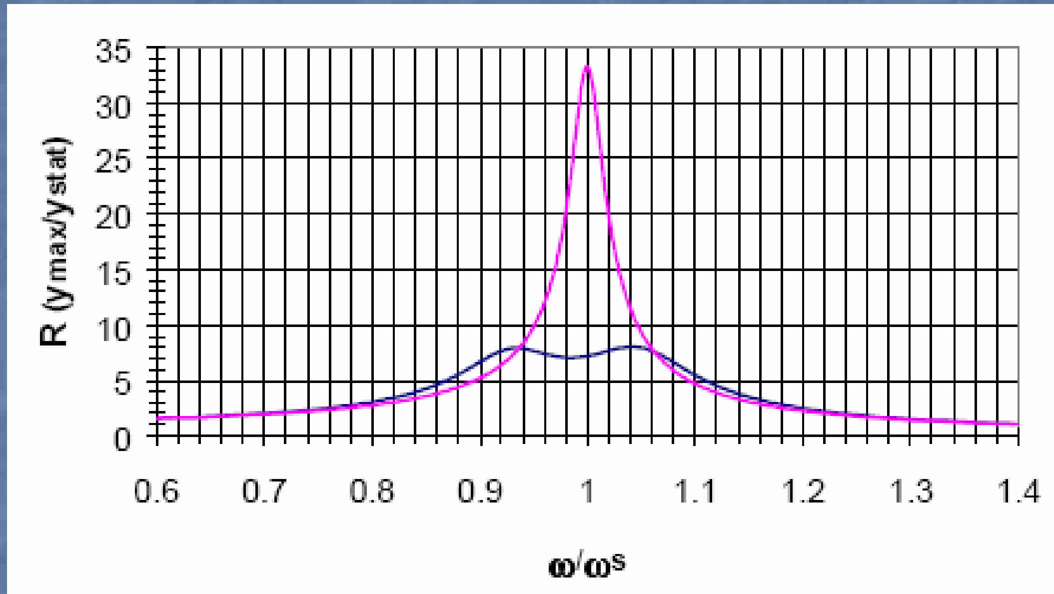


Fire station building Napoli

Ex Dipartimento di Matematica Federico II

CONTROL BASED ON INERTIAL FORCE

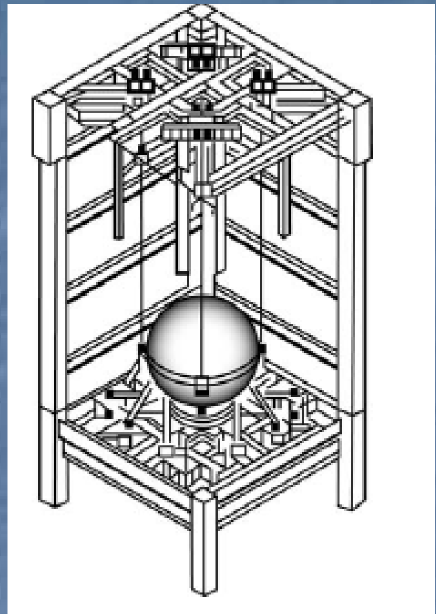


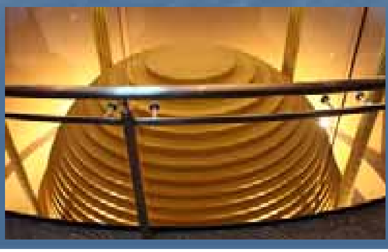


Equation of the Controlled Structure

$$M\ddot{x}(t) + C\dot{x}(t) + Kx(t) = F(t) - m_s \ddot{X}_s(t)$$

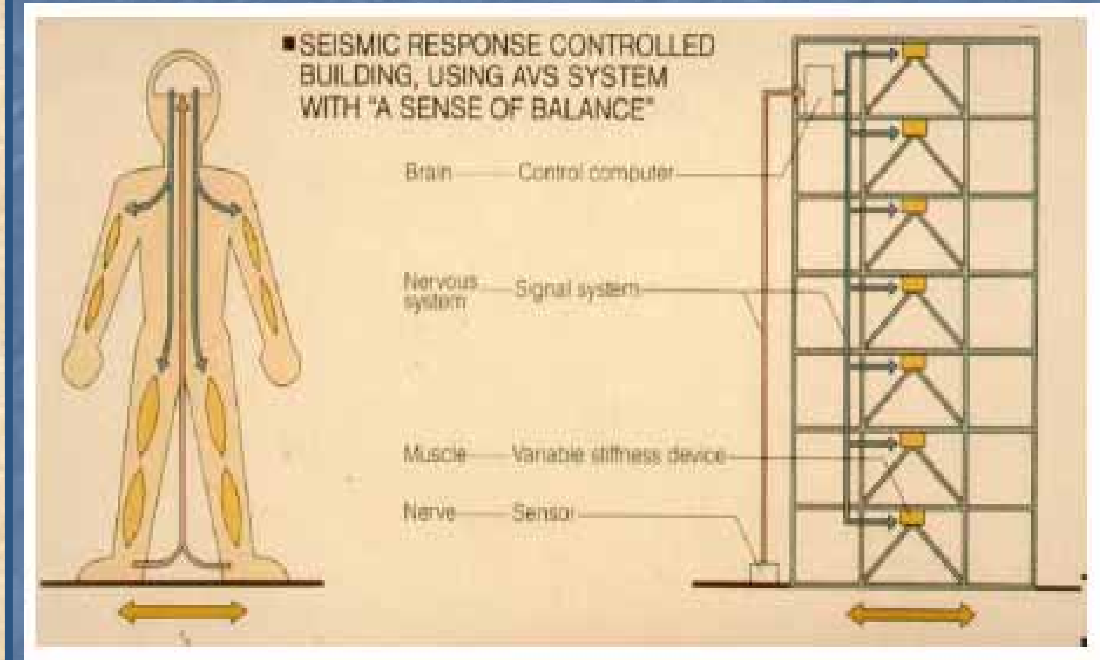
TUNED MASS DAMPER





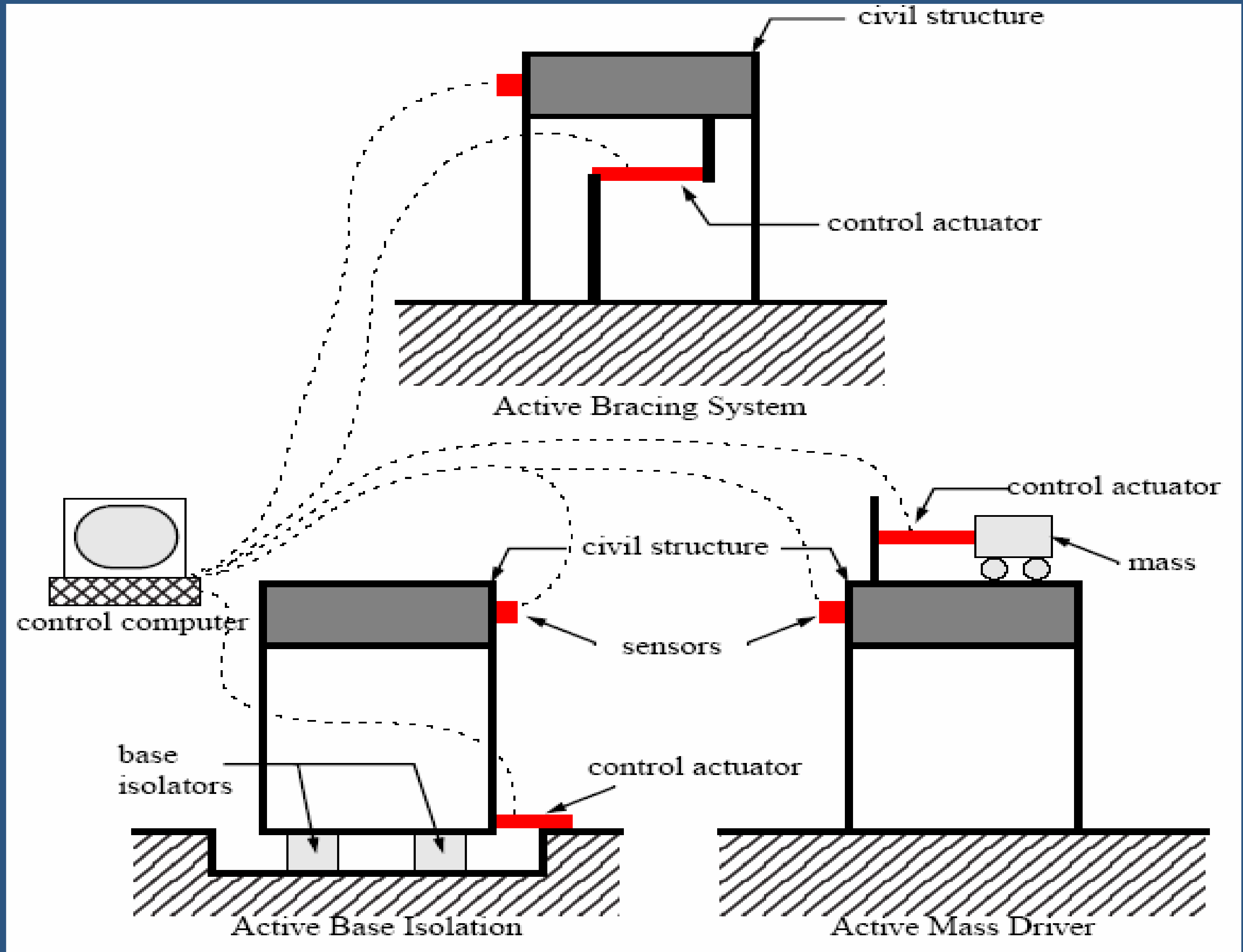
ACTIVE AND SEMI-ACTIVE CONTROL

Systems capable to self-regulate instantaneously their properties as a function of the structural response. Motion data are taken from a sensor network, analysed in real time by a computer and elaborated in such a way to activate external devices (active control) or just to modify the mechanical properties of these (semi-active-control).



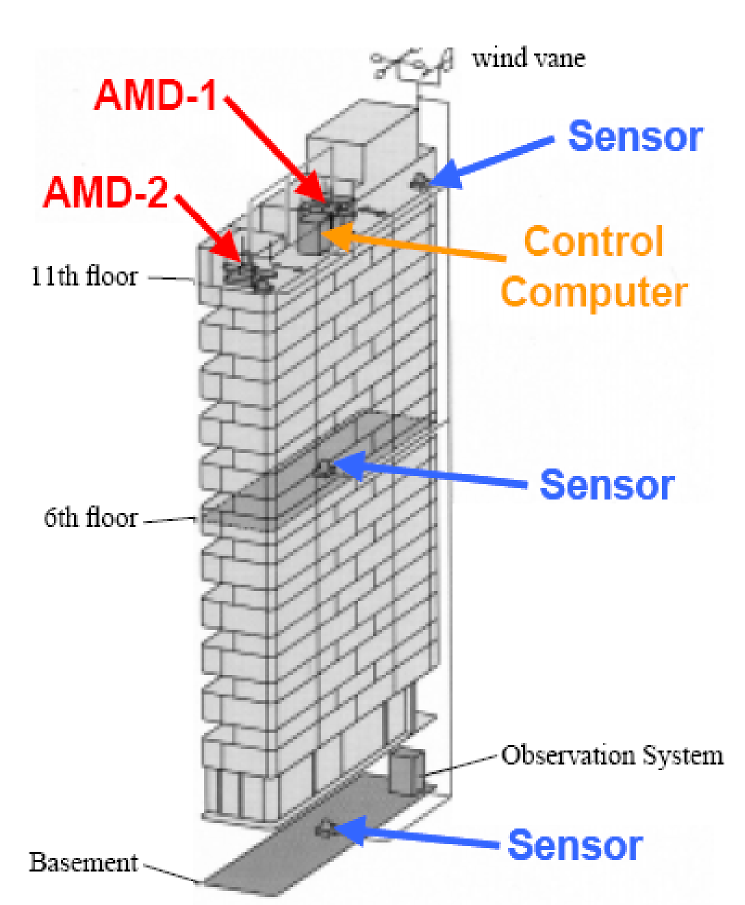
ACTIVE STRUCTURAL CONTROL – Structural implementation

Main methodologies of seismic active and semi-active control of civil structures



ACTIVE STRUCTURAL CONTROL – Structural implementation

Kyobashi Seiwa Building - Tokyo (1989) – 33.1 m heigt, floor dim 4 x 12 m
First building in the world to have an active control system
2 AMD installed at the top of the structure
to suppress vibrations caused by earthquakes and strong winds



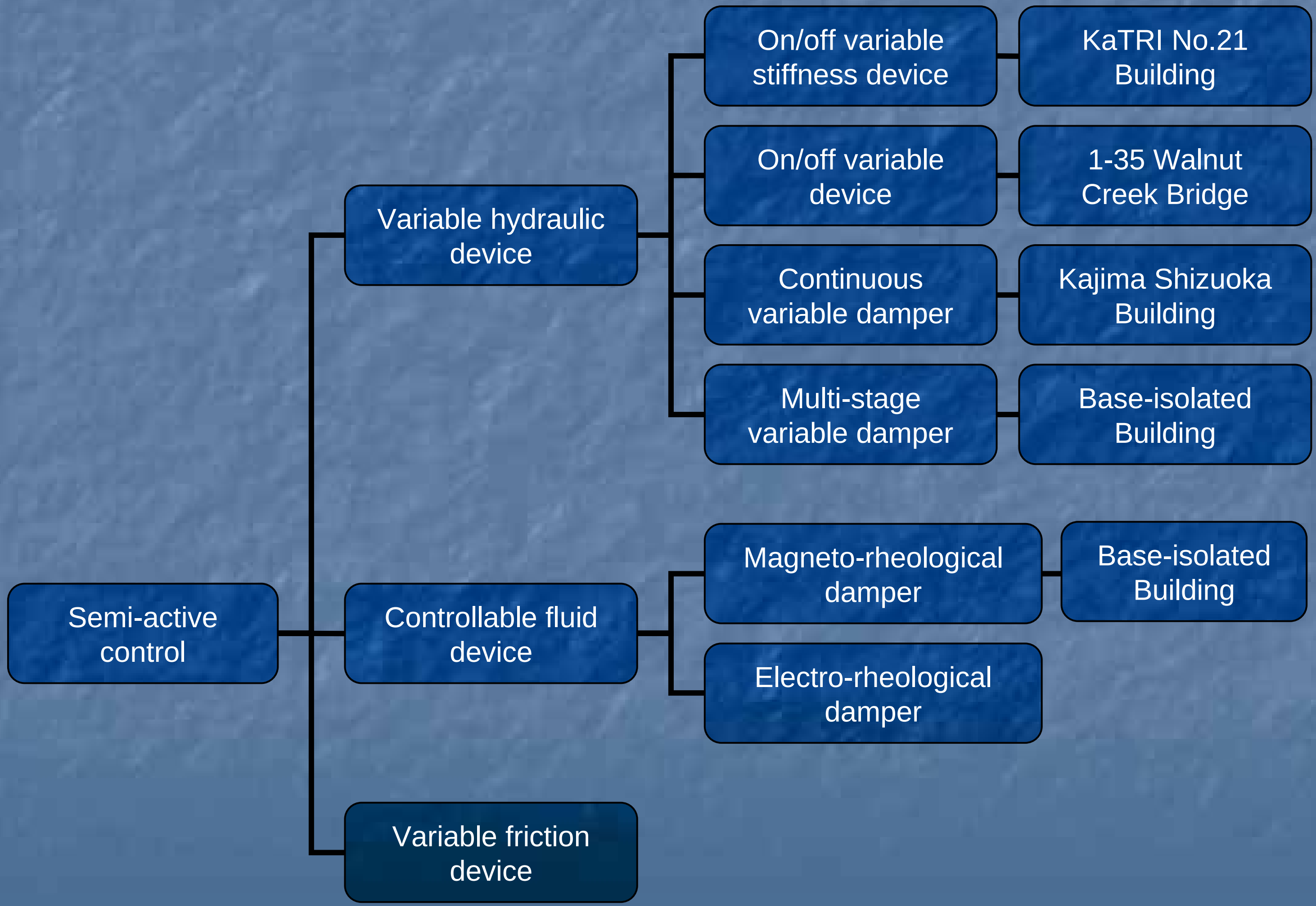
There are actually:
over 40 buildings and towers implemented with active control strategies and
15 bridge towers implemented with active and hybrid control devices

Some Full Scale Structure with active control

- Sendagaya INTES Tokyo, Japan 1992
  58m, 3280 ton, 11 stories
- Osaka Resort City 2000, Osaka, Japan 1992
  200m, 56980 ton, 50 stories
- Landmark Tower, Yokohama, Japan 1993
  296m, 260610 ton, 70 stories
- Richga Royal Hotel,Hiroshima, Japan 1994
  150m, 83000 ton, 35 stories
- TC Tower Kao Hsung, Taiwan 1996, 85 stories
- Nanjing Tower Nanjing, China 1998, 310 m

SEMI-ACTIVE STRUCTURAL CONTROL – Smart devices

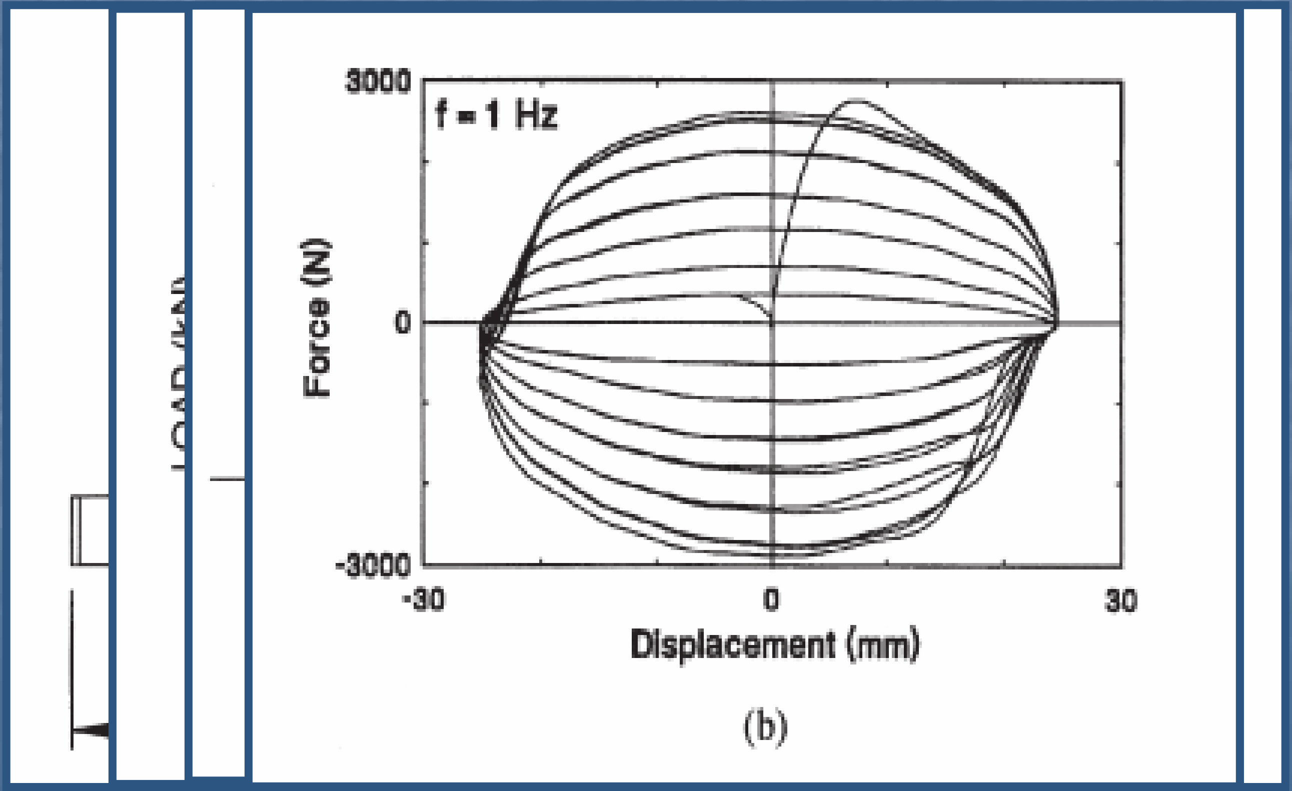
Low power requirement, passive working, small dimensions



Variable Viscous Devices

In viscous devices the dissipative mechanism depends on the load application velocity.

Variable orifice devices



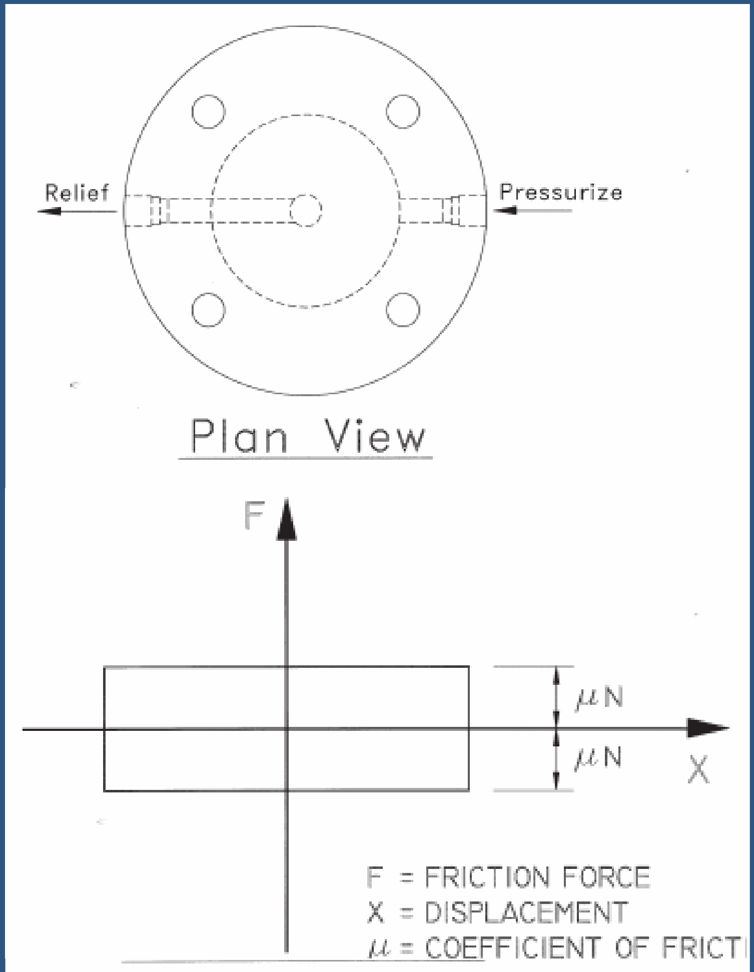
(b)

$$F(t) = C(V)\left|\dot{x}\right|\operatorname{sgn}(\dot{x})$$

SEMI-ACTIVE STRUCTURAL CONTROL – Smart devices

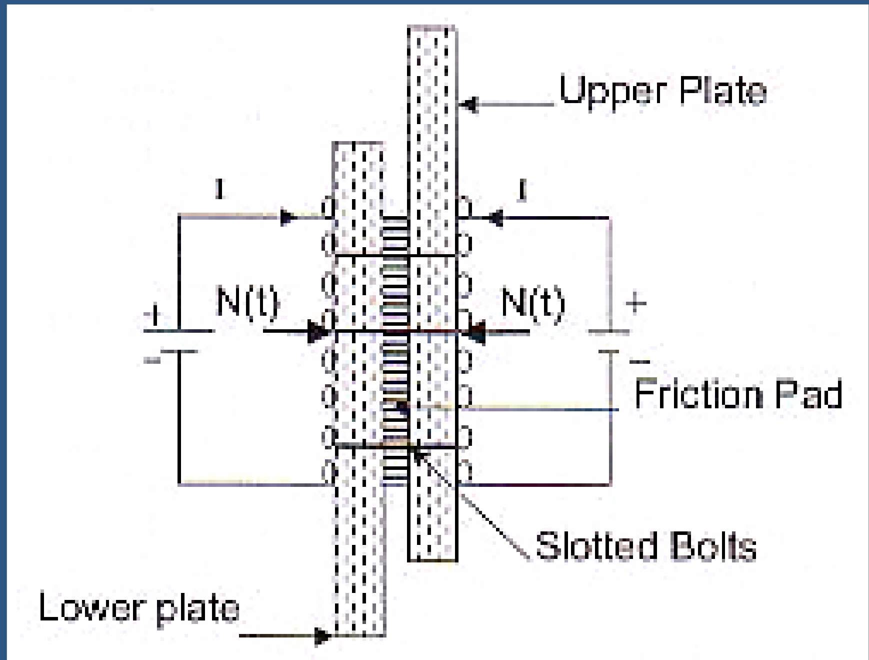
Variable Friction Devices

They are based on the effect of friction → varying the pressure on the sliding plates



Variable friction devices

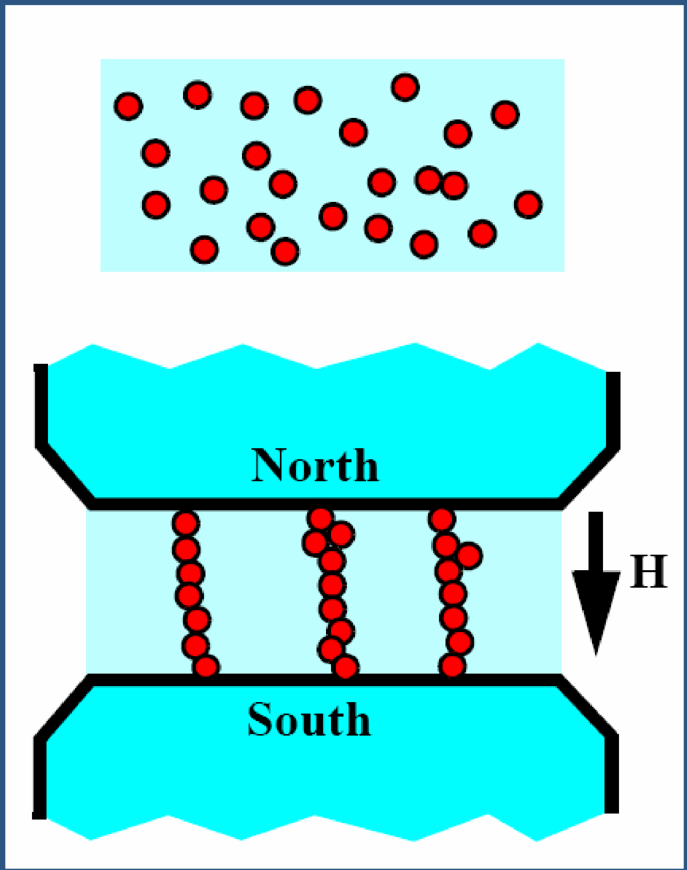
$$F = \mu \cdot N \,\mathrm{sgn}(\dot{x})$$



SEMI-ACTIVE STRUCTURAL CONTROL – Smart devices

Controllable fluid dampers

They are based on the properties of special fluids which can modify their properties in few milliseconds when immerged into an electro-magnetic field

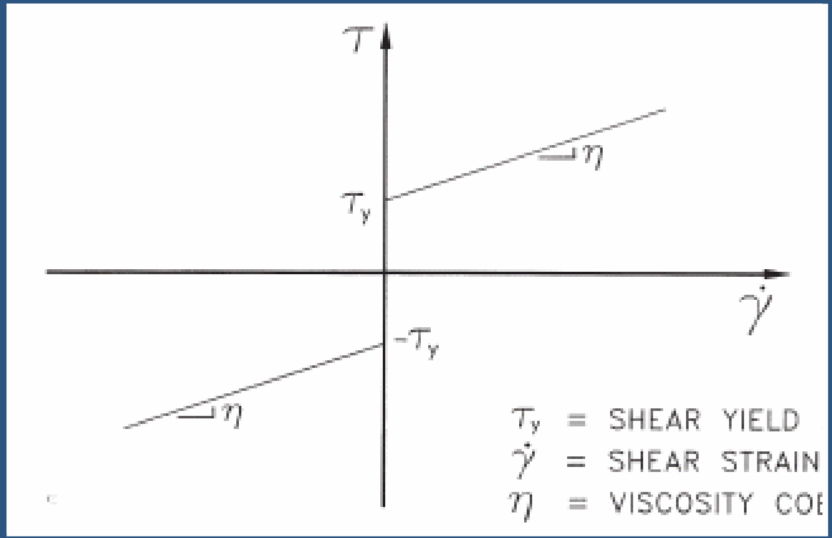


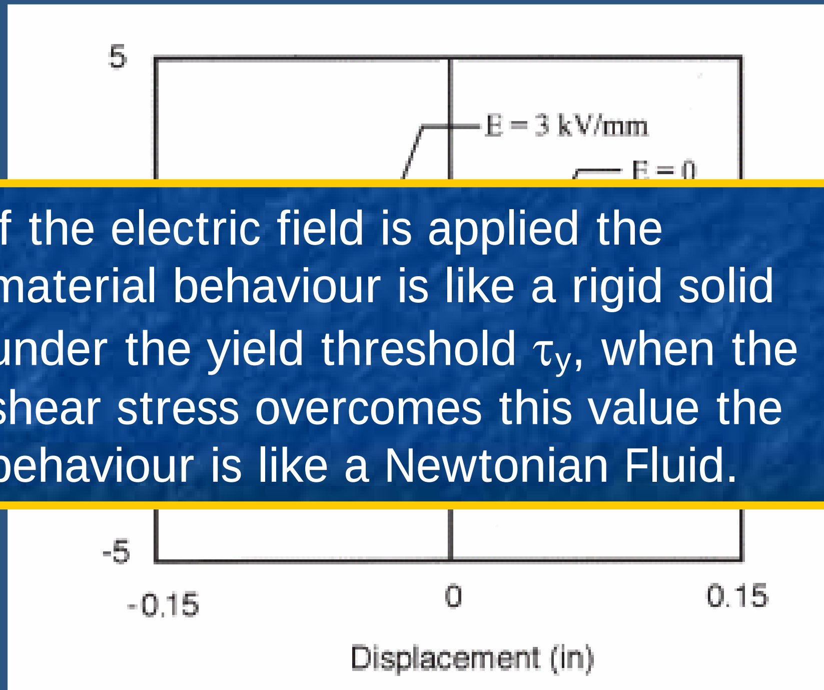
SEMI-ACTIVE STRUCTURAL CONTROL – Smart devices

Electro-rheological fluid dampers

They are used for real-time modification of structural stiffness and damping

$$\tau = \tau_y \,\mathrm{sgn}(\gamma) + \eta \dot{\gamma}$$



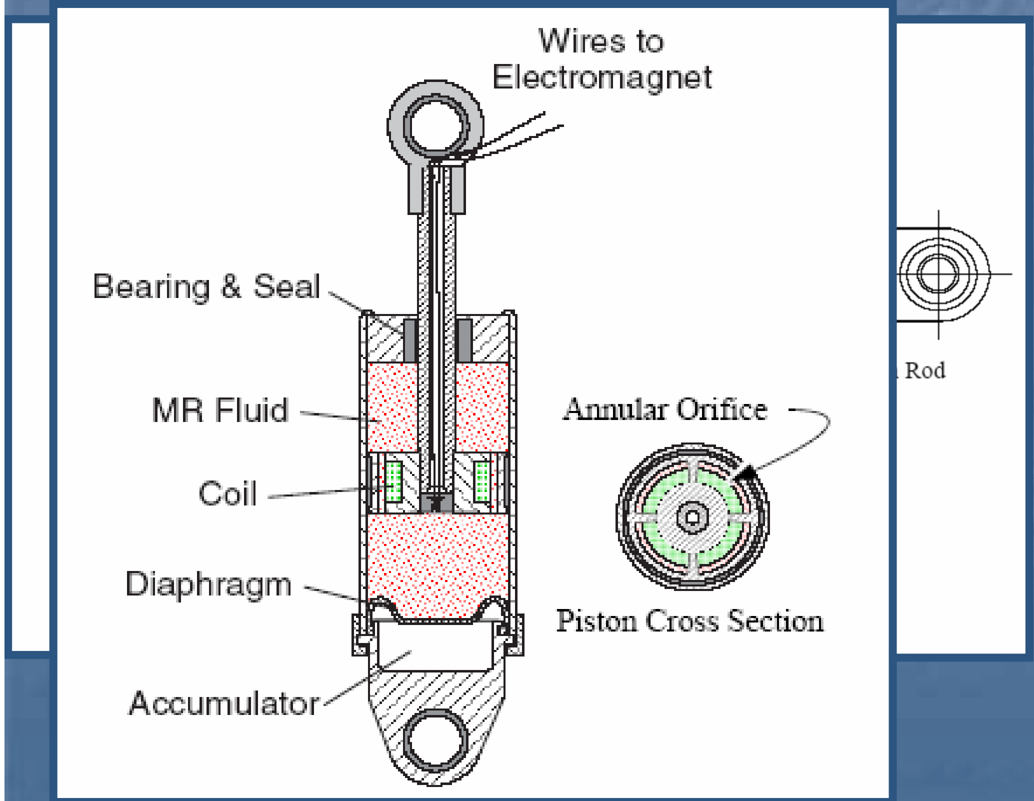


if the electric field is applied the material behaviour is like a rigid solid under the yield threshold τ_y, when the shear stress overcomes this value the behaviour is like a Newtonian Fluid.

SEMI-ACTIVE STRUCTURAL CONTROL – Smart devices

Magneto-rheological fluid dampers

Suspension of micron-sized magnetizable particles in an appropriate carrier liquid, able to reversibly change from free flowing linear viscous liquid to semisolid having a controllable yield strength (100 kPa order), in milliseconds, when exposed to a magnetic field



A typical MR fluid is made of 20%-40% of iron particles suspended in a mix of mineral oil, sinthetic oil and water (or alcool)

Bingham visco-plastic model

$$\tau = \tau_0(H)\,\mathrm{sgn}\left(\dot{\gamma}\right) + \eta\gamma \qquad |\tau| \geq |\tau_0|$$

$$\dot{\gamma} = 0 \qquad |\tau| \leq |\tau_0|$$

DESIGN OF MR DEVICE

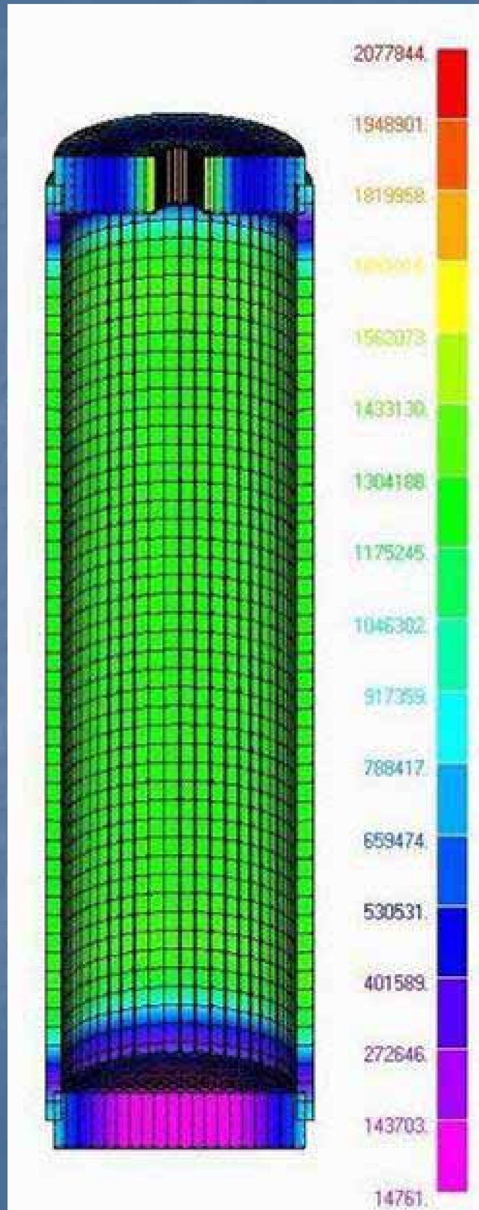
***F**$_{max}$* **= 5000 kN**
R_i = 41.5 mm
h = 3.5 mm
v_0 = 2.0 m/s
R_p = 50.0 mm
η = 0.1 Pa s(*)
τ_{MR} = 15.0 kPa(*),(**)

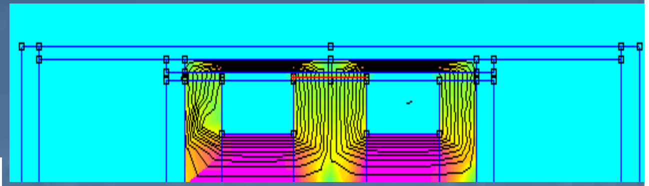
(*) Value referred to the MRF 132AD fluid by Lord Corporation
(**) For a current of 1.0 A.

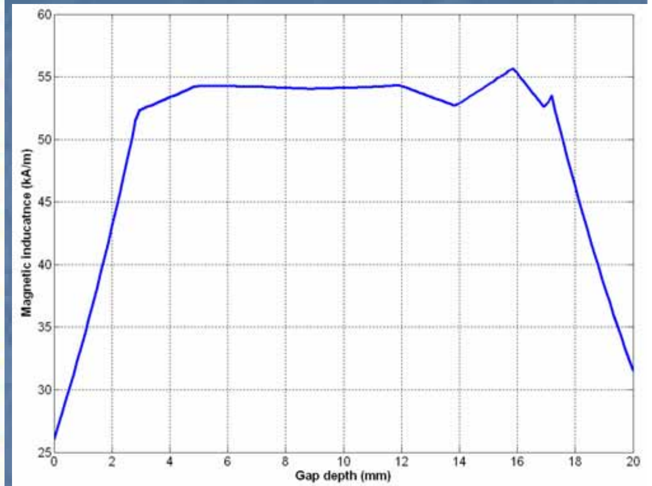
$$\Delta P = \Delta P_f + \Delta P_{MR} = 12\eta \frac{QL}{bh^3} + 3\frac{L}{h}\tau_{MR}$$

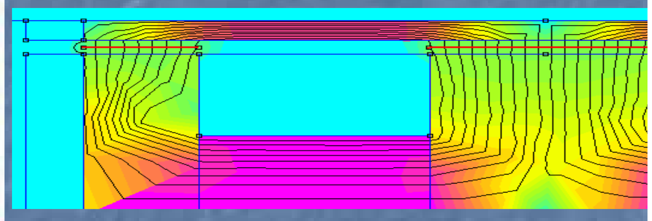
$$r = \frac{\Delta P_f}{\Delta P_{MR}} = \frac{12\eta \frac{QL}{bh^3}}{3\frac{L}{h}\tau_{MR}} = 4\eta v_0 \frac{R_p^2}{(R_i + R_e)h^2 \tau_{MR}}$$

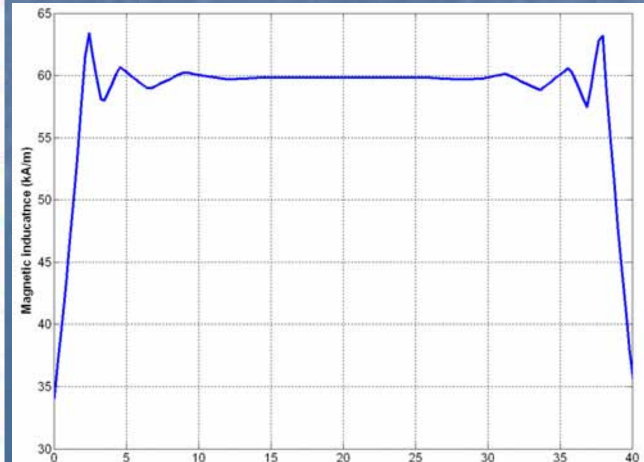
$$L = \frac{h}{2\tau_{MR}}\Delta p_b$$





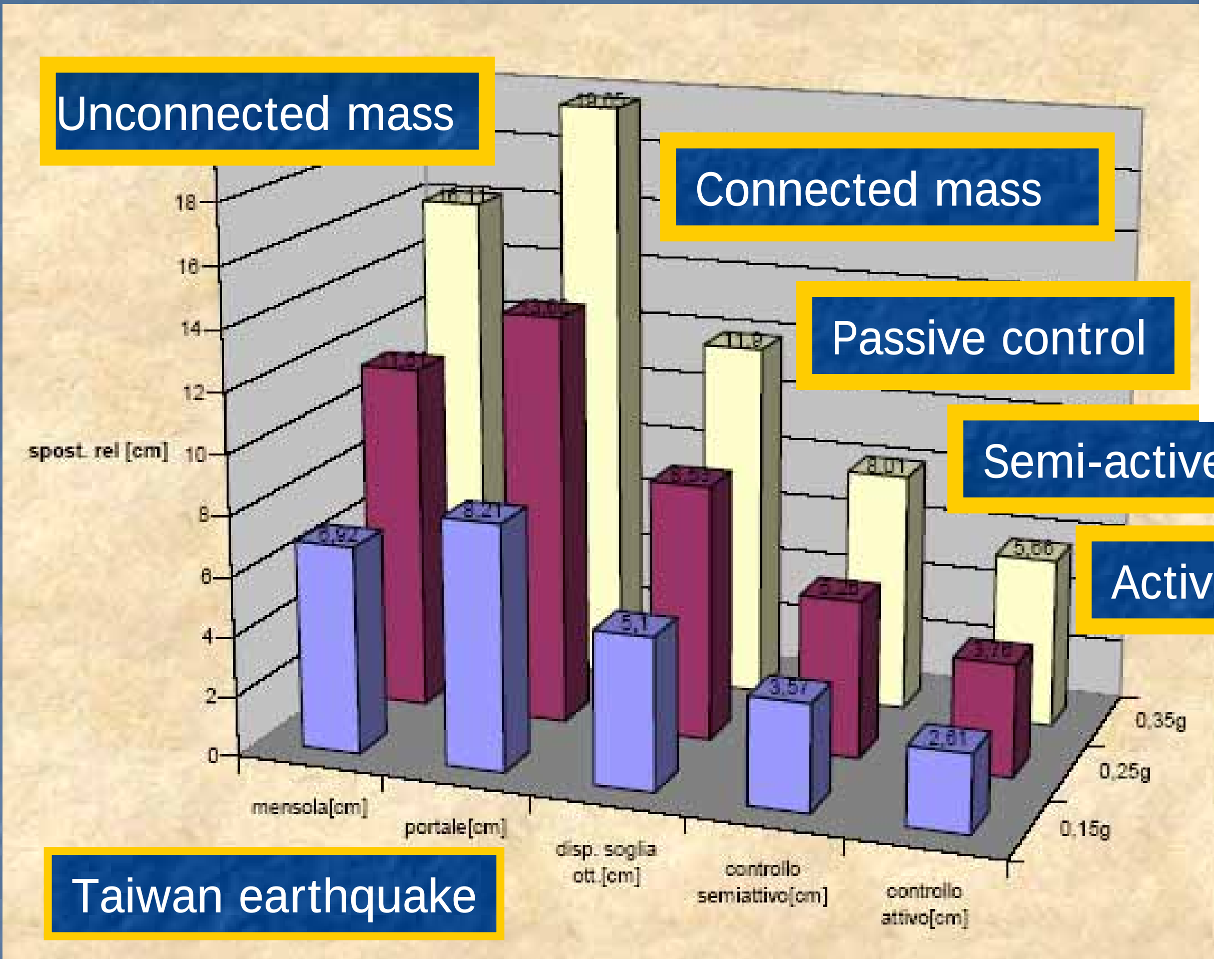


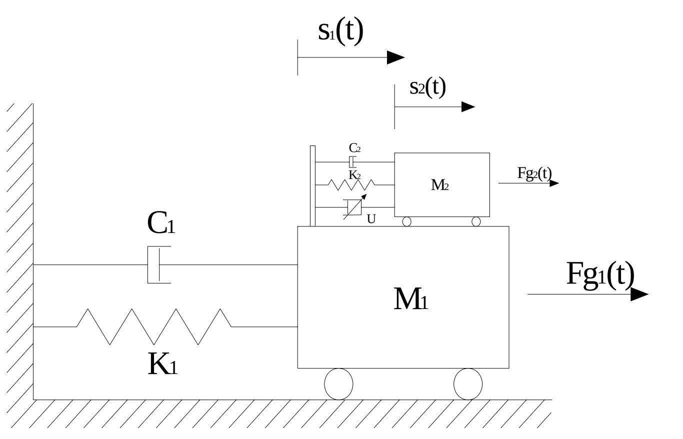




DESIGN OF MR DEVICE

ACTIVE STRUCTURAL CONTROL – COMPARATIVE NUMERICAL ANALYSIS





	mensola[cm]	portale[cm]	disp. soglia ott.[cm]	controllo semiattivo[cm]	controllo attivo[cm]
0,15g	6,92	8,21	5,1	3,57	2,61
0,25g	11,51	13,66	8,53	5,25	3,76
0,35g	16,11	19,65	11,9	8,01	5,66

CONCLUSIVE REMARKS

- Materials and technologies available today represent an effective tool against any potential risk related to catastrophic seismic events;
- The outlined solutions can be effectively tailored to the design of both new buildings and retrofit operations;
- Innovative solutions in principle allow to provide the structure with a given predetermined safety level corresponding to any design requirement;
- A new design approach based on structural robustness could be set out based on the use of advanced seismic protection techniques;

THANK YOU VERY MUCH FOR YOUR ATTENTION!